Vol. IV, No. 3 December, 1917

THE ANNALS OF APPLIED BIOLOGY

THE OFFICIAL ORGAN OF THE ASSOCIATION OF ECONOMIC BIOLOGISTS

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LONDON: FETTER LANE, E.C. 4
EDINBURGH: 100, PRINCES STREET
also
H. K. LEWIS & CO., LTD., 136, GOWER STREET, LONDON, W.C. 1
WILLIAM WESLEY & SON, 28, ESSEX STREET, LONDON, W.C. 2
PARIS: LIBRAIRIE HACHETTE & CIE.
CHICAGO: THE UNIVERSITY OF CHICAGO PRESS
BOMBAY, CALCUTTA AND MADRAS: MACMILLAN & CO., LTD.
TORONTO: J. M. DENT & SONS, LTD.
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VOLUME IV DECEMBER, 1917 No. 3

ON THE LARVAL AND PUPAL STAGES OF *BIBIO JOHANNIS* L.

BY HUBERT M. MORRIS, M.Sc. (MANCH.).

(*From the Department of Agricultural Entomology, Manchester University.*)

(With Plate II and 12 Text-figures.)

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1. INTRODUCTION AND HISTORICAL REMARKS.

During the early part of 1917 I found in the soil of a permanent pasture field at Holmes Chapel, Cheshire, a number of what appeared to be Dipterous larvae of the family Bibionidae, and Dr A. D. Imms suggested to me that a study of these larvae would form a very interesting piece of work.

Some of these larvae were reared and on emergence the fly proved to be *Bibio Johannis* L., for the confirmation of the identity of which I have to thank Mr H. Bury. To Dr Imms I desire to express my thanks for his assistance in many ways during the whole course of the investigation. The work has been carried out in the Department of Agricultural Entomology, Manchester University.

Hitherto there has been no complete account of any Bibionid larva, but only partial descriptions and fragmentary accounts of the life-history.

On account of the frequent occurrence of larvae of this family, and their possible economic importance in certain cases, I have been led to investigate the present species as fully as possible.

The earliest description of the larva and pupa of any species of *Bibio* met with, is that given by Reaumur (1741). Reaumur describes and gives figures of the larva and pupa of the "St. Mark's Fly" (*Bibio Marci*), but, as with all other figures of larvae and pupae of this genus seen, the figures are not sufficiently clear for purposes of identification of species. De Geer (1776) gave the first account and figures of *Bibio Johannis* and in 1832 Lyonet gave a description of *Bibio Marci*. Bouché in 1834 described and figured the larva and pupa of *Bibio hortulanus*, and also figured the mouth parts of the larva, but these figures again are very indefinite. Westwood in 1840 referred briefly to the larva of this genus and gave a small figure. In 1872 Beling described the larvae and pupae of a number of species of *Bibio* and *Dilophus*, amongst others those of *Bibio Johannis*. Needham in 1902 gave an account of the occurrence of swarms of the larvae of *Bibio fraternus*, with descriptions and figures of the larva and pupa, while Sharp (23) has figured a larva of an unnamed species of *Bibio*, and has also given a figure of a portion of the integument of the larva.

In addition to these accounts there are several records of the finding of larvae of different species of *Bibio* in great numbers in a small area (13) and references to damage done by them to cultivated plants. The larvae of the different species of *Bibio* appear to be very similar, which makes identification of the larvae difficult.

2. THE EGG.

The egg (Text-fig. 8, p. 112) is ·63 to ·66 mm. long and ·13 to ·15 mm. broad. It is cylindrical with rounded extremities, and is approximately straight. The eggs are not shiny but have rather an opalescent appearance owing to their being covered with small pointed projections. They are at first of a uniform light straw colour but after a few days a darker patch appears at each end.

3. Morphology of the larva.

(*a*) Newly hatched larva.

The eggs hatched under laboratory conditions in forty-eight days, on May 30th, which appears to be an exceptionally long period. The newly hatched larva is from 1·3 to 1·5 mm. in total length, of which the head measures about ·18 mm., with a breadth of ·16 to ·19 mm. The head is relatively large, yellow brown in colour, and bears a number of long setae.

The body is almost colourless, the contents of the alimentary canal showing through as a broad dark line. In shape it is cylindrical, but it is slightly curved, as in the adult. The body is divided into twelve segments, of which the first is the largest. Each segment bears a number of long slender setae, the length of which varies on different parts of the segment.

Between the long setae on each segment are a number of smaller projections on the cuticle, which correspond to the scale-like structures of older larvae. These projections each consist of a blunt conical base, bearing a single pointed seta, which is directed obliquely backwards. Of the long setae those on the sides are the longest, except on the last and penultimate segments, on which segments those setae situated dorsally are the longest. Each of the long setae arises from a base similar to, but larger than, those of the small setae (Text-fig. 11, p. 112).

The young larva bears a single pair of spiracles, which are situated on the last segment in a corresponding position to that occupied by the spiracles of this segment in the fully grown larva. At the present stage each spiracle has only a single opening.

The structure of the spiracles is similar to that of the spiracles on segments three to ten of the adult larva, but they project very little from the body.

From the extremity of the last segment the larva is able to protrude a pair of membranous conical structures, one on either side of the anus. These structures are protruded by blood pressure, and withdrawn by means of special muscles attached to them. They assist the larva in its movements in a similar manner to the pseudopodia of other larvae.

The head at this stage is very similar to that of the full-grown larva. The antennae, maxillae and labrum show very slight differences from the adult form. The mandibles are shorter at this stage, and their teeth are relatively longer. The groups of setae on the mandibles are present,

but they are not so well developed as in the full-grown larva, the setae being shorter and fewer in number.

In the labium, the submentum is rather less stout than that of the full-grown larva, the anterior projections are longer and sharper, while between them is a third projection.

Alimentary Canal. The alimentary canal of the young larva is similar to that of the adult larva. The caeca are rather wider in proportion to their length, and are filled with a yellow fluid. The peritrophic membrane is present as a straight delicate tube lying inside the mesenteron, and extending from its anterior end to about the point at which the posterior caecum opens into the digestive system. The Malpighian tubes are similar to those of the fully grown larva, entering the alimentary canal by a common duct, but the tubes are not enlarged at their point of union. They are colourless, but contain numerous light yellow granules.

Tracheal System. From each spiracle of the pair on the last segment a single short trunk passes inwards, dividing into two on entering the body. One of these branches passes forwards laterally, giving off a fine transverse branch in each segment which connects with the main lateral trunk of the other side; in each segment, except the second and eleventh, a short branch is given off which passes outwards to the cuticle, but has no opening to the outside (Text-fig. 12, p. 114).

From the transverse connective in the first segment, and from the main lateral trunks, a number of branches enter the head and are distributed there.

From the lateral trunks in the eleventh and twelfth segments and from the transverse connective in the twelfth segment a number of fine branches are given off which pass to the heart.

The second of the two branches (into which the trunk from the spiracle divides on entering the body) again divides into a number of finer branches. Most of these branches are distributed in the twelfth segment, but one branch passes forwards, and divides into two at the end of the eleventh segment. The finer of these branches passes to the loop in the alimentary canal, while the other passes forwards into the head outside the main longitudinal trunk. This lateral trunk connects with the branch which passes outwards from the main trunk in each segment, except the second and eleventh.

Circulatory System. The heart lies in segment eleven and in the anterior part of segment twelve; it is continued forward as a dorsal vessel of slightly narrower calibre, to the anterior end of the body.

The heart has a small posterior chamber, provided with a pair of lateral openings by means of which the blood enters. These openings are closed by means of valves when the heart contracts, thus forcing the blood along the dorsal vessel. The latter is very thin walled, the nuclei of the cells of which it is composed bulging inwards into the vessel. The blood is a colourless fluid containing relatively large colourless corpuscles which are usually oval in shape.

Nervous System. The nervous system is similar to that of the full-grown larva. The supraoesophageal ganglion lies in the front of the first segment with the suboesophageal ganglion beneath it. The first thoracic ganglion lies in the posterior region of the first segment, the second is similarly situated in the second segment, while the third ganglion lies rather more forward in the third segment. The eight abdominal ganglia lie in the posterior half of their segments, except the eighth, which is in the front of the eleventh segment.

(*b*) Second stage larva.

The larvae passed into the second stage after nineteen days, under laboratory conditions.

This larva is much more like the full-grown larva in external appearance than is the newly hatched form.

The head does not appear relatively so large, while the long setae on the body have disappeared, the body now bearing processes similar to those of the fully grown larva. The cuticle also bears scale-like structures similar to those of the full-grown larva, but somewhat smaller. The spiracles on the last segment are larger but each has still only a single opening. A smaller pair of spiracles is situated on the first segment as in the full-grown larva, and there is also a still smaller pair of spiracles on the tenth segment. From this latter pair of spiracles the outwardly directed branches from the main longitudinal trunks in that segment take their origin. The tracheal system is similar to that of the first stage larva, but it has more numerous branches.

The mouthparts are very little different from those of the first stage larva, but are slightly more like those of the full-grown larva.

(*c*) Fully grown larva.

(*a*) *External Form.* The larva is 10 to 11 mm. long by 1·2 to 1·3 mm. wide and its thickness is a little less than its width. Of this length about ·9 mm. is the length of the head, which is of slightly less

width than length. The larva is clearly divided into two distinct regions, (i) The *Head* and (ii) The *Body*.

The *Head* is very clearly defined and is invested by a shining chestnut-brown chitinous capsule which is darker and stronger than the covering of the body. The head can be slightly retracted, so that the posterior end is covered by the front of the first segment of the body. It is darker in the anterior half and on that half bears a few long single setae, while the posterior half, which is lighter, is bare. From the centre of the hind edge of the head arises a fine dark line which passes forwards and almost immediately divides into two, which curve outwards to the bases of the mandibles (Plate II, fig. 5).

The paired appendages of the head are the antennae, mandibles and the first maxillae. Between and below the maxillae there lies a rather peculiar shaped plate. This structure probably represents the second maxillae fused to form a single organ. This plate has another rather crescent shaped plate lying above it. A similar structure often occurs in Dipterous larvae. The lower plate is regarded by Miall and Hammond (17) as the sub-mentum, while the upper plate is regarded as the mentum, which, they consider, has gradually slipped behind the sub-mentum.

The sub-mentum is dark and strongly chitinised, with a central lighter area bearing a group of short setae (Text-fig. 7, p. 112).

There does not appear to be any indication of eyes, and the antennae (Text-fig. 6, p. 112) are small and inconspicuous. The mandibles (Text-fig. 4, p. 111) are large, strong and dark, and have each two large teeth and two smaller ones. They bear on their inner side a prominent group of fine setae some of which are slightly branched.

The maxillae (Text-fig. 5, p. 111) are stout and have a distinct palp. The tops of both palp and maxilla bear a number of setae.

The *Body* is nearly cylindrical, but is slightly flattened dorso-ventrally and normally is curved slightly, the ventral surface forming the inside of the curve. The body consists of twelve segments, of which the first is the longest and has rather the appearance of two segments, but the imaginal discs prove it to be a single segment.

The body bears ten pairs of spiracles which are brown in colour and are situated, a pair on each segment, on all segments except the second and eleventh. The spiracles are situated laterally except those on the twelfth segment which are placed more dorsally than the others. The spiracle on the first segment (Text-fig. 1, p. 110) is about twice the size of those on the third to tenth segments, and that on the twelfth segment

is about four times the size of those on the third to tenth segments (Text-figs. 2 and 3, p. 110).

The first segment (Plate II, fig. 1) is divided dorsally into two slightly raised areas, of approximately equal size, by a transverse groove. On the first of these areas are six processes, arranged in a transverse row, those towards the sides being about twice as long as those in the centre. The ventral side is similarly divided into three areas, of which the second is below the first dorsal area, but is curved back in front, and a smaller, roughly triangular, area is formed in front of it, on which are two short processes. On the second area are two short processes in the centre, one about four times as long on each side, and one on each side of intermediate length between those at the sides and those in the middle. On the third raised area are six processes of which the longest, at the sides, are as long as the intermediate ones on the second area. The spiracle on this segment is situated laterally and slightly farther back than the second row of spines on the dorsal side, and projects from the side a distance equal to its own diameter.

The second segment is divided dorsally into three areas in the same manner as the first segment. Of these areas the first bears a process on each side, and the second a row of six processes. Ventrally the same division is visible, the first area bearing two central processes, and the second a row of six processes.

The third segment is similar to the second, but bears a pair of spiracles laterally on the front part of the first raised area.

The fourth segment is also divided into three areas, and bears on the front of each side of the first raised area a spiracle, and on the middle area a transverse row of six processes. Ventrally, it has a row of six processes on the first area, and another row of six processes on the second; the two lateral processes of the latter row appearing behind and a little below the spiracle.

The fifth to tenth segments are similar to the fourth.

On the eleventh segment the row of six dorsal processes are much enlarged; of these, the middle pair are the largest and the lateral ones one-third the size. About the middle of the ventral side of this segment is a row of six processes similar to those on the preceding segments. There is also a lateral process on each side half-way between the dorsal processes and the front edge of the segment (Plate II, fig. 4).

The four processes on the dorsal side of the twelfth segment are also much enlarged, and are situated on the hind margin of the segment. There is, furthermore, a short process on the middle of the side of the

ventral surface. The spiracles of the twelfth segment are situated halfway between the lateral processes of the dorsal row, and the front of the segment, and they project twice as much as the preceding spiracles (Plate II, fig. 4). These spiracles have each two openings, while the other spiracles have only one.

The body is covered by a tough cuticle which is actually of a light brown colour, but the larva appears darker owing to particles of soil adhering to it, and to the dark contents of the alimentary canal. The cuticle bears small irregular shaped scale-like structures, which do not touch one another. These structures are of various sizes, and the larger ones are rather conical and bear from one to eight short and usually backwardly directed spines (Plate II, figs. 7 and 8). On the bases of the processes, and on the spiracles of the larva, these structures are closer together and give a more scale-like appearance, while on the processes the spines become considerably longer than elsewhere.

Each intersegmental region bears a row of depressions which vary considerably in shape. They are placed side by side (Plate II, fig. 6) and apparently similar structures are situated, often singly, on other parts of the segments. These depressions are of a darker colour than other parts of the cuticle, and are surrounded by elongated spineless scale-like structures.

On the twelfth segment the scale-like structures form a closer covering, which has rather the appearance of a squamous epithelium. The spines of the scale-like structures on the dorsal surface of this segment are very much reduced or absent, except on the processes, while on the ventral surface a single stouter spine is present on each scale.

From the end of the twelfth segment the larva can protrude pseudopodium-like structures similar to those of the newly hatched larva, but at this stage they are relatively smaller.

(*b*) *Internal structure.* The *Integument* consists of a chitinous cuticle, with the hypodermis or chitogenous layer underlying it.

The *Cuticle* consists of two layers, of which the outer is considerably the thinner, is of a light yellow colour in sections, and is highly refractive, except in the head, where the outer layer is of greater thickness than elsewhere, and is of a brownish yellow colour in sections. The inner layer, which is relatively thick, appears to be only partially chitinised and is more readily stainable than the outer.

The *Hypodermis* appears to be an undifferentiated stratum of protoplasm containing scattered oval nuclei which are hard to distinguish, no cell wall being distinguishable. Below the hypodermis and in contact

with its inner surface, is a layer of flattened, irregular-sized cells. Miall and Hammond(15) consider that these are the "Wandering cells." In this larva this sub-hypodermal layer of cells appears to be continuous. The scales consist of a thin stratum of the outer layer of cuticle, which is not continuous beneath them, the interior of the scale being occupied by cuticle of the inner layer. The hypodermis does not enter the scales although it bulges outwards slightly towards their bases. The processes are of similar structure, the hypodermis bulging upwards barely to the base.

The Digestive System.

The alimentary canal takes a nearly straight course through the body from the front of the head to the end of the last segment, but it is slightly longer than the body. It is divided into Fore-Gut, Mesenteron or Mid-Gut, and Hind-Gut, and is provided with salivary glands, caeca and Malpighian tubes (Text-fig. 9, p. 113).

The *Fore-Gut* extends from the mouth to the end of the first segment of the body.

The *mouth* is formed by the labrum above, the mandibles at the sides and the labium and maxillae below. The inner surface of the labrum (the epipharynx) bears numerous short setae, the arrangement of which is shown in Text-fig. 6, p. 112. Some of these setae are probably sensory while others may assist in holding and cutting the food.

The mandibles are mostly used in taking the food into the mouth, and are moved in the same, or almost the same plane, but their shape causes the food between them to be worked against the epipharynx, which bulges slightly downwards. Just behind the mouth the fore-gut dilates slightly into the *pharynx*, from the walls of which muscles radiate to the walls of the head, and circular muscle fibres are present in its walls.

The *Oesophagus* (Text-fig. 9) is a straight and narrow tube of simple structure. It is lined by a chitinous intima, which is considerably folded. Outside the intima, is an epithelium in which the nuclei can be seen but not the cell walls. Outside the epithelium lies a muscular coat, consisting of a layer of circular fibres, forming a series of transverse rings. On the outside of the muscular coat is a thin membrane of connective tissue. Towards the middle of the first segment of the body the oesophagus dilates slightly, and the intima here becomes stronger and has the appearance of small groups of teeth. Behind this is a short region or *Gizzard* with very strongly developed circular muscles and of

smaller diameter (Text-fig. 9). The oesophagus ultimately joins the cardia or first portion of the mesenteron, at the end of the first segment.

The *Salivary Glands*. The salivary glands are rather small, and lie one on either side of the alimentary canal, towards the end of the first segment. Each gland is hollow and has a lining of protoplasm. Strands of protoplasm also stretch across the interior of the gland forming a complicated network in which, as well as in the lining of the gland, are large nuclei. The salivary duct passes forwards ventrally from the anterior end of each gland.

The oesophagus is continued a short distance into the cardia, and is then sharply turned back and passes upwards again to the point where the epithelium of the cardia begins, forming an *oesophageal valve*. The part of the oesophagus forming the valve is very similar in structure to that of other parts as far as the first bend. It consists of intima, epithelium, and well-developed circular muscle fibres. The part of the oesophagus between the two bends is composed of an epithelium of much larger cells than the other part, without the muscle fibres. The space between these two parts forms a blood sinus, and is crossed by bands of connective tissue fibres, and there are also bands of longitudinal muscle fibres between the two portions of the oesophagus.

The part of the cardia which follows the oesophagus, and surrounds the valve, consists of deeply staining columnar cells, followed by less deeply staining cells, and this tissue makes several folds into the cardia. These folds chiefly involve the epithelium, but also the moderately developed coat of circular muscle fibres to a small extent. From the anterior part of the cardia a number of bands of muscle fibres stretch to the walls of the oesophagus, without resting on the alimentary canal throughout their length.

From the cardia the three large *caeca* take origin; the longest, which lies parallel to the mesenteron and ventral to it, is about 2·5 mm. long. The other two, which are of about equal length (1·3 to 1·4 mm.), open laterally from the cardia and are slightly inclined upwards.

The caeca are composed of an epithelium similar to that of the mesenteron, the cells of which are rather larger and project slightly into the lumen. Outside the epithelium is a membrane of connective tissue, but no muscle fibres. The caeca are filled with a finely granular substance.

The *Stomach* which follows the cardia has walls of the following structure, from within outwards:

1. The peritrophic membrane, which forms a thin-walled tube lying loose within the stomach from the cardia to near the end of the stomach.

2. The epithelial layer is composed of cells with rather large and dark-staining nuclei, and in some parts a distinct "striated margin" was seen.

3. The basement membrane, outside which is—

4. The muscular coat consisting of poorly developed bands of circular and longitudinal muscle fibres.

5. The connective tissue, which lies outside the muscular coat.

The thickness of the epithelium varies slightly in different parts of the stomach, and it gives off protrusions into the cavity which are finely granular, and feebly staining.

From near the posterior end of the stomach a fourth caecum opens on the ventral side. This caecum is smaller than the others and lies parallel to the stomach with its closed end forwards. Its walls are of a similar structure to those of the other caeca, but are considerably folded near the attached end. The cells of all four caeca show a well-marked "striated margin."

The *Hind-Gut* commences in the ninth segment, but its length is considerably increased by the formation of a loop. It is divided into three parts, the *ileum, colon* and *rectum* (Text-fig. 9).

The *Ileum* commences as a slight dilation, and is lined with a layer of epithelium composed of rather large cells, slightly rounded on the inside, and bounded by a fine intima. The epithelium rests on a basement membrane, outside which is a strongly developed coat of circular muscle fibres outside which again are longitudinal muscle fibres, the whole being covered by a thin connective tissue membrane. The circular muscles are very close together, each band touching those next to it. At the commencement of the ileum the circular muscles are particularly well developed.

The *Malpighian tubes* are four in number, and at their attached end they are dilated for a short distance to about twice the diameter of the remainder of their length.

The four dilated ends join together and join the anterior end of the ileum by a short common duct, which lies on the left of the alimentary canal.

The tubes are covered on the outside with a delicate membrane, inside which is a lining of protoplasm containing numerous large nuclei which bulge into the cavity of the tube. The nuclei of the dilated part

are smaller than the others but more numerous. The protoplasm contains many fine granules.

The *Colon*, which follows the ileum, is of rather larger diameter, and is less muscular than the ileum. It has a fine intima, outside which is a layer of epithelium rather thinner than that of the ileum. The colon is invested with circular muscle fibres similar to those of the ileum, but they are neither so large nor so close together. Externally the colon is covered with a delicate connective tissue membrane.

The *Rectum* is of considerably smaller diameter than the colon. Its epithelium and intima are deeply folded, filling up much of the gut. The muscular coat is well developed and composed of circular muscles, with a connective tissue membrane outside them.

The *Nervous System.* The nervous system of the *Bibio Johannis* larva consists of a brain or supraoesophageal ganglion, a suboesophageal, three thoracic and eight abdominal ganglia. The brain is two-lobed and lies in the anterior part of the first segment of the body. The two lobes are distinct but are closely connected.

The suboesophageal ganglion lies directly below the brain, and is connected with it by short but fairly fine oesophageal connectives, which connect its anterior end with the anterior end of the lobes of the brain. The head is almost entirely filled with the muscles of the mouthparts, so that the brain is displaced into the first segment. In this latter region, in larvae near pupation, the rudiments of the adult head may be also found.

The first thoracic ganglion lies just behind the suboesophageal, and is nearly as large, the second is close behind it while the third is farther back. The first ganglion is situated at the posterior end of the first segment, the second lies in the front of the second segment and the third in the front of the third segment.

The abdominal ganglia are smaller, and are situated one in each segment. The first seven ganglia lie in the anterior region of their respective segments. The last abdominal ganglion is considerably larger than the others, and is situated toward the hinder region of the eleventh segment.

In the head is a small frontal ganglion which is connected with the brain.

The connectives between the ganglia are clearly double throughout.

From the ganglia lateral nerves are given off, the distribution of which was not studied.

The Tracheal System[1].

From each spiracle except those on the last segment a single tracheal trunk passes inwards, and on passing through the integument it divides into three branches. One branch at once divides into a number of fine branches while the other branches connect with the spiracles before and behind, these connectives also giving off fine branches to the tissues.

From each of the openings of the last pair of spiracles a single trunk passes inwards, and each one then divides into two branches.

4. HABITS, FOOD, ETC.

The larvae of *Bibio Johannis* were found near the surface of the soil, amongst the roots of the grasses of the pasture. The soil near the surface was very rich in organic matter in all stages of decomposition, as the field had been pasture for a number of years. The soil was a medium loam on the surface, but becoming heavier a few inches down.

The larvae were usually found at a depth of not more than half an inch below the surface, and some appeared to be actually on the surface of the soil; they were usually in small colonies, in which the larvae were very close together.

The larvae fed by working particles of soil and organic matter into the mouth by the rather slow movement of the mandibles.

From examinations made of the contents of the alimentary canal it appeared that these larvae had been feeding on decaying vegetable matter only, as only such material and inorganic particles were found.

Several observers record having found the larvae of species of *Bibio* in cow-dung, horse-dung (8, 15) and in other situations where there has been a very high proportion of decaying vegetable matter, as in garden soil (26) and at the base of decaying tree stumps (19). It appears also that larvae of this genus can feed on the roots of living plants.

The larvae of *Bibio Johannis* are moderately active and are able to bury themselves in loose soil fairly quickly, assisted probably by their backwardly directed processes.

The larvae and pupae, contrary to the experience of Malloch (15) were not found difficult to rear. They were reared in medium sized glass jars, partially filled with soil, grass, etc., similar to that amongst which the larvae were found, the jars being covered with coarse muslin and the soil kept damp. As it was desired to obtain the fly rather early in the

[1] The spiracles have already been described on pp. 96–98.

year, the larvae were kept under cover in a temperature which was always above that outside.

Although the larvae were found during the latter half of an unusually severe winter, they appeared but little affected by the cold and did not descend into the soil to any distance as far as was observed.

No parasites were met with in connection with these larvae, and the only reference to parasites met with in this family, is that of Malloch (15). This observer mentions a hymenopterous parasite of whose connection with this family of hosts he is uncertain. Lyonet mentions finding a "louse" on a *Bibionid* larva, and a *Filaria* inside one.

5. COMPARISON WITH LARVAE OF OTHER DIPTERA.

The structure of the larva of *Bibio Johannis* indicates that it is very primitive, the larva having twelve complete segments, a comparatively large head that cannot be withdrawn into the first segment, and well-developed mouthparts.

The presence of ten pairs of spiracles is very unusual, and is characteristic of the family. The fact that the spiracles of the first and twelfth segments are considerably larger than those of the other segments seems to indicate a tendency for the larva to become amphipneustic instead of peripneustic. Of the mouthparts, the most noteworthy is the labium, which is modified in a similar way to that of *Chironomus* and *Dicranota* (16, 17). Three caeca is an unusual number, many caeca being found in *Chironomus*, eight in *Anopheles* and a few other larvae, four in a number of species, and two in others.

The posterior caecum is also unusual although Dufour found a "caecum latéral" in *Tipula lunata*, which, however, opened from the intestine and not from the mesenteron as is the case in the *Bibio Johannis* larva. Four is a common number of Malpighian tubes, but they usually enter the alimentary canal separately.

The oesophageal valve is fairly primitive, considerably more so than that of *Simulium* or *Chironomus* (16, 17) or *Anopheles* (12). It considerably resembles the valve figured by Holmgren (11) in *Mycetophila ancyliformans*, but is relatively shorter.

The structure of the cardia is also similar to that shown by Holmgren, in having first a regular epithelium of columnar cells, followed by a considerably folded region. In *Bibio Johannis* however there is a space between the two parts of the oesophagus forming the valve, which contains muscle fibres, and is more like that of *Dicranota*.

The peritrophic membrane is very common in Diptera, its length varying considerably. In this larva as in many others the membrane appears to arise from the anterior end of the cardia.

In the general features of its morphology the larva of *Bibio Johannis* bears a closer resemblance to the larvae of the Mycetophilidae than to any other group. This resemblance appears to be due to the fact that the two families are phylogenetically closely related. The possibility, however, that certain of the characters may be the result of convergence due to similarity of habitat must not be overlooked.

6. THE PUPA.

The larvae pupated on March 25th, the pupa being formed in an oval cell of soil, the last larval skin being in the cell with the pupa. The cell was considerably larger than the pupa, and quite smooth, and looked as if it had been formed by the larva pressing outwards in all directions.

The pupa is 7 to 8 mm. long, about 2 mm. broad across the thorax and 1·3 to 1·5 mm. broad across the abdomen.

The cuticle is smooth and white at first, but soon appears darker as the parts of the imago darken and show through owing to the transparency of the cuticle. The abdomen throughout is light in colour, as the abdomen of the imago does not darken completely until after it has emerged.

The pupa of the female is distinctly larger than that of the male particularly in the width of the abdomen.

The head is flat below and is pressed down on to the prothorax. The antenna cases are short and extend little more than half way across the eyes. On the anterior end of the head is a stout process directed forwards, which covers the ocelli of the imago. The cases of the mouth-parts are distinct. The thorax is short and thick, and the mesothorax is considerably the largest segment.

The leg-cases lie side by side, touching those of the other side in the median dorsal line, and extend to about the middle of the first abdominal segment. The cases of the first pair of legs are wholly visible, those of the second pair almost so, while only the extremities of the third pair are left in sight. The remainder is covered by the wing-cases, which do not quite meet and extend a little farther back than the leg-cases (Plate II, fig. 3).

Dorsally there is a slight ridge running from the posterior edge of the mesothorax to the process on the head, and along this ridge the cuticle splits for the imago to emerge (Plate II, fig. 2).

The prothoracic spiracles project slightly in a dorso-lateral position. The boundary between the prothorax and the mesothorax is not marked on the dorsal side, while ventrally the leg- and wing-cases cover almost the whole of the thorax. The abdomen is long, straight and slightly flattened dorso-ventrally and consists of nine segments, the first six of which are about equal. After the sixth segment the abdomen tapers slightly, the last segment having the form of a blunt cone. The last segment bears a pair of stout processes slightly dorsally near its tip, which are nearly as long as the segment.

Apart from these processes and the spiracles, the cuticle of the pupa is bare.

The abdomen bears a pair of spiracles on each segment except the eighth. These spiracles project from slightly before the middle of the sides of the segments.

7. NOTE ON THE IMAGO.

The adults emerged from the pupa on April 9th and the following days, but their emergence was probably hastened by the warmer conditions under which they were kept.

The number of individuals of the different sexes, including the pupae which were preserved as well as the adults which emerged, were, males 20, females 7, showing a considerable preponderance of males.

8. ECONOMIC SIGNIFICANCE OF THE BIBIONIDAE.

There appears to have been a considerable amount of uncertainty as to whether larvae of this family are destructive to the roots of cultivated plants. A number of instances are recorded of such damage by certain species of this family, although Scharov (22) considers them harmless.

Various species are recorded by Theobald (26) as attacking the roots of oats, grass, lettuces, seedling cabbages and young flower plants, while hops appear to be particularly badly attacked, especially by *Dilophus febrilis* and *D. vulgaris* (20, 27).

Carpenter (4) reports finding larvae of *Bibio Marci* feeding on potatoes, while Collinge (5) states that *Bibio Marci* damages tomatoes, young conifers, seedling ash and young spruce. He further adds that *Bibio Johannis* damages larch seedlings and hop roots, and he considers that these larvae are introduced in manure or leaf-mould. The larvae of *Bibio Marci* are also recorded by Gillanders (10) as injuring ash seedlings.

Other records mention *Bibio hortulanus* larvae as damaging sugar beet(25), spring barley and wheat(18), the damage in the latter instance being so severe that many fields had to be ploughed up and resown.

Curtis(6) states that *Dilophus febrilis* larvae cause much mischief in gardens. He found them on the decayed portions of planted potatoes and also on the tubers, and in flower pots.

Larvae of *Bibio abbreviatus* are reported by Strickland(24) to have damaged celery plants. The soft tissue between the fibro-vascular bundles of the stalks was eaten away to a depth of 1·5 mm., and the larvae also burrowed slightly into the stalks. Owing to the large number of larvae the damage was extensive. In this case the larvae are thought to have been brought to the plants in manure.

Some instances of believed damage by the adults of this family are recorded. Lyonet(14) believed that the adults of *Bibio Marci* damaged the buds of fruit trees, and other writers believed that the adults of this family damage fruit blossom, but it is unlikely that the damage was due to this cause, the flies being more probably beneficial in assisting pollination(31). The adults of *Dilophus febrilis* are mentioned as being believed to cause damage to hop-cones, but any damage is probably due to their being dried in the cones(27).

Bibio albipennis, which appears to be very common in the United States of America, is considered to be harmless. The larvae are said to feed on dead leaves and stems(7), and they are also mentioned as having been found feeding on oak galls(29), which appears unusual, unless the galls had fallen to the ground.

The larvae of Bibionidae appear to occur very commonly in cow-dung and manure(8, 15) and it seems probable that in many instances the larvae have been carried to the plants which they were found damaging in manure. Many of the plants mentioned as being attacked are usually grown with heavy applications of this material.

Theobald(27) states that vaporite and injections of bisulphide of carbon into the soil were found to kill the larvae. He also recommends trapping the larvae by burying old roots in the soil, and then digging them up early in March and destroying the larvae found feeding on them. He also found soot and lime effective in dealing with the larvae.

Carpenter(4) states that the larvae "seemed to be but little affected by the dressings usually applied for killing or repelling underground insects." He states that various birds, including domestic poultry, devour the larvae readily. *Bibio* larvae of several species have been found in the food of rooks, starlings and chaffinches(28).

Spraying infected land with a solution of Chili saltpetre in early spring, and harrowing in autumn or early spring after spreading quicklime on the field are recommended (25), while ploughing deeply and rolling at the time of pupation, has also been found satisfactory (18), contact poisons being said to have very little effect.

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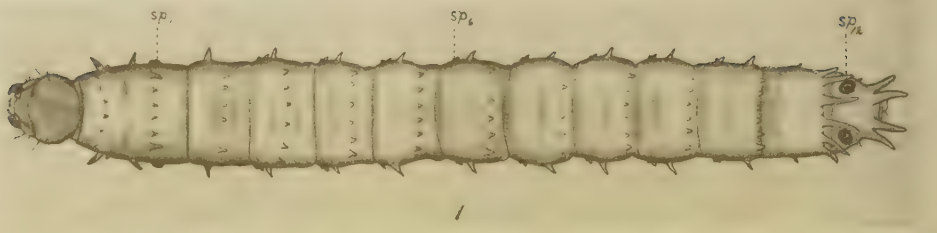

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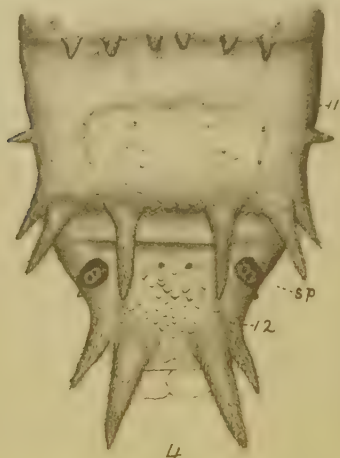

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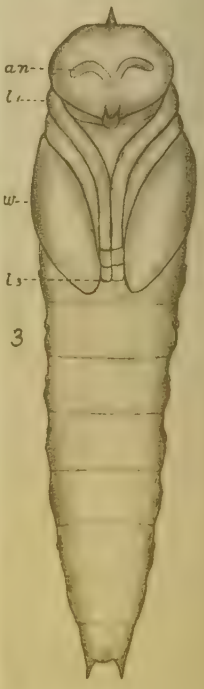

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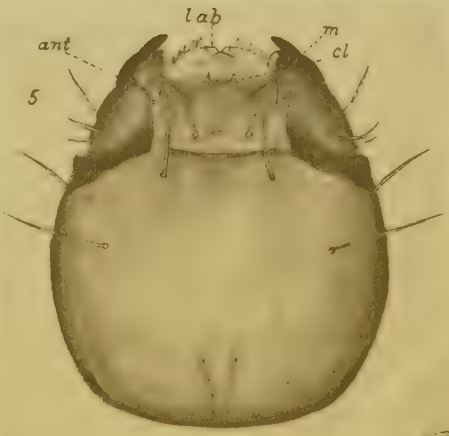

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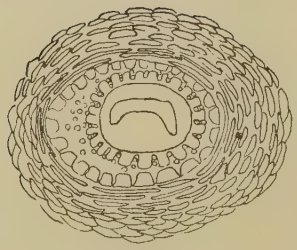
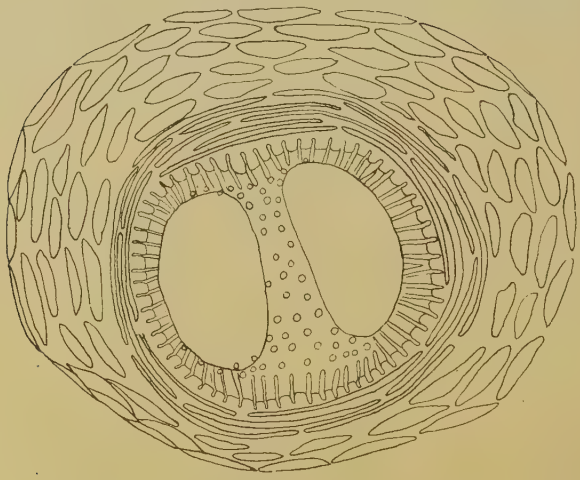
10. DESCRIPTION OF PLATE II.

Fig. 1. Almost fully grown larva of *Bibio Johannis*, dorsal aspect. *sp.* spiracle of first segment; $sp._6$ spiracle of sixth segment; $sp._{12}$ spiracle of twelfth segment. × 12.
Fig. 2. Pupa of *Bibio Johannis*, dorsal aspect. *ps.* prothoracic spiracle. × 12.
Fig. 3. Pupa of *Bibio Johannis*, ventral aspect. *an.* antenna case (right); *l.* leg-case of right leg of first pair; $l._3$ leg-case of right leg of third pair; *w.* wing-case (right). × 12.
Fig. 4. Posterior end of larva, dorsal aspect. 11, eleventh segment; 12. twelfth segment; *sp.* spiracle of twelfth segment. × 30.
Fig. 5. Head of larva, from above. *ant.* left antenna; *lab.* labrum; *m.* right mandible; *cl.* clypeus. × 60.
Fig. 6. Part of an intersegmental region, surface view. × 180.
Fig. 7. Portion of cuticle, surface view. × 180.
Fig. 8. Ditto, lateral view. × 180.



Text-figure 1. Left spiracle of first segment of larva. ×360.

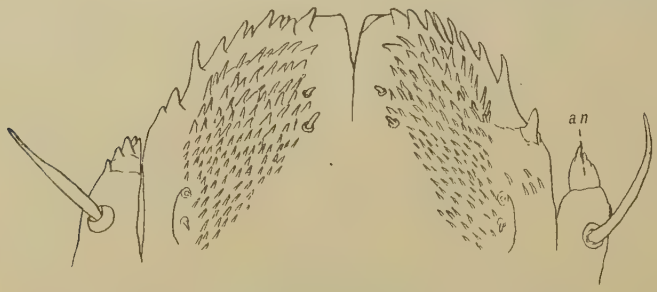
Text-figure 2. Left spiracle of sixth segment of larva. ×790.



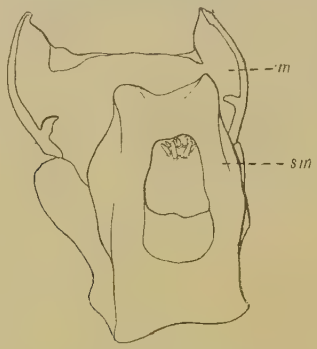
Text-figure 3. Right spiracle of last segment of larva. ×360.

Text-figure 4. Right mandible of larva viewed from the left. ×180

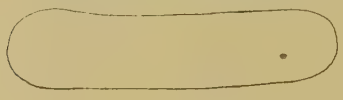
Text-figure 5. Right maxilla of larva from below. ×180.
p, maxillary palp.



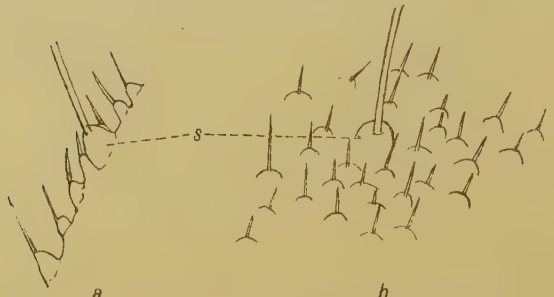
Text-figure 6. Labrum of larva from below. *an*, antenna. ×200.



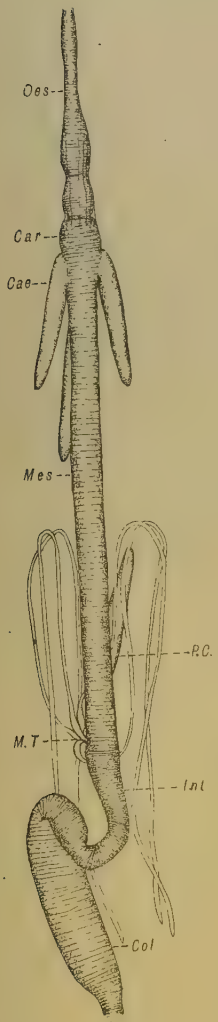
Text-figure 7. Labium of larva from below. ×200.
m, mentum. *sm*. sub-mentum.



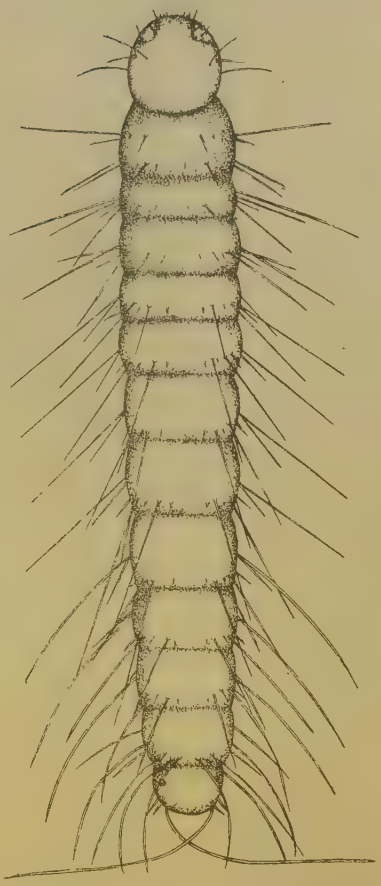
Text-figure 8. Egg of *Bibio Johannis*. ×80.



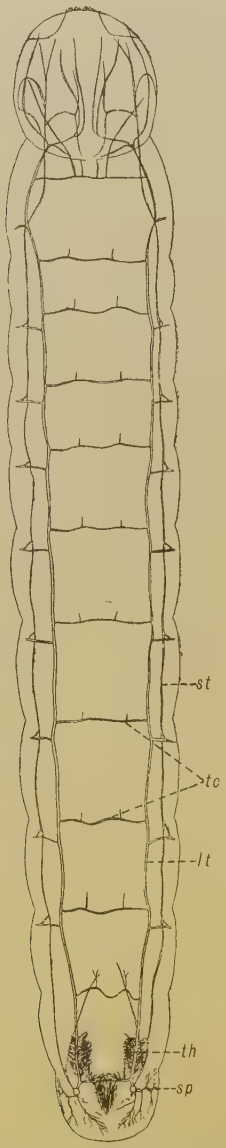
Text-figure 11. Processes on cuticle of newly hatched larva. ×600.
a, Lateral view; *b*, surface view. *s*, base of long seta.



Text-figure 9. Alimentary canal of *Bibio Johannis* larva. *Oes*, Oesophagus. *Car*, Cardia. *Cae*, Caeca. *Mes*, Mesenteron. *P.C.* Posterior caecum. *M.T.* Malpighian tubules. *Int*, intestine. *Col*, Colon.



Text-figure 10. Newly hatched larva of *Bibio Johannis*, dorsal aspect. ×90.



Text-figure 12. Tracheal System of newly hatched larva. × 120. *lt*, Main longitudinal trunk. *sp*, Spiracle. *st*, Secondary longitudinal trunk. *tc*, Transverse connectives. *th*, Tracheae to the heart.

TWO EXPERIMENTS IN HOUSE FUMIGATION

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House fumigation with hydrocyanic acid gas or carbon bisulphide is no new thing and some years ago Mr C. W. Mason and I fumigated the greater part of the new laboratories of the Pusa Agricultural College, a building over 400 feet long. But in the cases I have had experience of the difficulties were slight and in the present cases were considerably greater.

In the first case the house was situated in one of the suburbs and was infested with the house mite (*Glycyphagus domesticus*, etc.). The use of paraffin, formalin and sulphur dioxide in single rooms had driven the mites over the whole house and the lady of the house was in despair, having struggled without success for some years. It seemed likely that only very drastic treatment in every part of the house simultaneously would succeed and it was necessary that this should not simply mean the rooms but the floors, staircases, outhouses and even the coalshed.

It is known that hydrocyanic acid gas has a very small power of penetration in grain and it was fairly certain that it would not penetrate the floors if simply generated in the room: so carbon bisulphide was used for floors and at the same time hydrocyanic acid gas was generated.

The house was an ordinary three story detached one with twelve rooms, no cellars or basement. The houses on each side were less than twenty yards away. The volume of the house was approximately 31 feet cube or 30,000 c. feet. The individual rooms were not measured but we tried to fill the whole house evenly and the amounts were allotted roughly according to the size of the room; all doors were left open inside the house.

The quantities employed were 40 lbs. cyanide 98 per cent., 40 lbs. sulphuric, and 54 lbs. carbon bisulphide. Including larder, bathroom, etc., 21 lots of cyanide and 23 lots of bisulphide were used as follows:

Cyanide: 1 lot of 6 lbs. in the hall;
3 lots of 3 lbs. in the larger rooms;
11 lots of 2 lbs. in the smaller rooms;
6 lots of $\frac{1}{2}$ lb. in the larder, etc.

Bisulphide: 1 lot of 4 lbs.;
7 lots of 3 lbs.;
14 lots of 2 lbs.;
1 lot of 1 lb.

The bisulphide was apportioned according to the floors, landings and staircases. The procedure was as follows; a list was made of the rooms and the special places requiring doses either of cyanide or bisulphide: on this the quantities were estimated, the chemicals were obtained and the owners went out. With the help of Messrs Davidson and Awati the fumigation was done between 10.30 a.m. and 1 p.m.

The acid and water was mixed in the yard in proper quantity for each room in a jug or basin and put there; the cyanide was weighed into pieces of cloth about 20 inches square and placed beside each basin; rooms were allotted and signals fixed: the bisulphide was then measured into jugs and placed beside the cyanide.

All being ready and the sequence of operations fixed for each floor, we commenced at the top, each pouring his dose of bisulphide down the floor and standing by with the cyanide: at the signal the cyanide was dropped into the acid and each man bolted out: in this way the floors were done: the most difficult was the ground floor, where there were seven charges of cyanide and nine of bisulphide to be let off by three men but we emerged without mishap.

The house had been prepared by closing all openings, opening out cupboards, books, etc., and taking up all carpets; where possible a plank was taken up in the floor. All fires were out, all chimneys closed, all gas off.

Success turned on penetration of the floors, which I hoped to secure by pouring down bisulphide. The strengths were worked out at 1 lb. of cyanide to 700 cubic feet and 1 lb. of bisulphide to 500 cubic feet, assuming each to penetrate the whole house. The hydrocyanic probably never penetrated the floors and the bisulphide did not saturate above floor level, so each was much stronger, certainly at first.

The cost of chemicals was:

	£	*s.*	*d.*
40 lbs. cyanide 98 per cent. fused at 1*s.* 2*d.*	2	6	8
40 lbs. sulphuric acid coml. at 1½*d.*	0	5	0
54 lbs. bisulphide at 4*d.*	0	18	0
	3	9	8

The house was visited twenty-six hours after the fumigation and the

fumes in the ground floor were then so strong that it was impossible to stay and I had difficulty in getting out. So the house remained shut for a total period of sixty-nine hours when it was then opened up.

The occupiers moved in a few days later and the lady of the house, who had waged war on the mites for years, searched and found live ones in the books and in one attic. A few days later they were found also on the banisters and on the piano. Apparently this was all and three months later the lady of the house wrote: "We shall not need any further fumigation for the present: indeed I am hopeful we are practically free of the mites. I have seen none on the furniture for some time though I fully expected to in the last week's warm weather." Two months later the house was reported clear entirely.

It seems likely that had the fumigation been repeated fourteen days later, even on a milder scale, every ultimate mite would then have been destroyed. It must be remembered that not only is there the egg as a resistant stage but also the curious hypopial stage, in which the mite encases itself and passes into a resting stage. In either of these forms fumigation would scarcely kill all in the most sheltered positions. The experiment showed (as far as one alone can), that:

1. Cyanide and bisulphide can be used together.
2. The escaping vapours are not offensive to neighbouring houses.
3. Gas escape from an ordinary house is slow.
4. Bisulphide vapour escapes slowly from ordinary ventilated floors (these not being closed).
5. The cost of fumigation is not excessive.
6. Neither gas damages the contents of a house.
7. A single application at these strengths may be sufficient, by destroying practically all the mites and making further increase impossible.

From observation of the results it appeared as if the bisulphide was not very effective even at this strength: one larder was treated very heavily with bisulphide as it contained food that might absorb the hydrocyanic acid: yet here mites were found.

The second case may be more shortly told. It was a two story house of 18,000 cubic feet capacity, heavily infested with book-lice (*Psocidae*), which were of the usual wingless type found in houses. The infestation had lasted from April to August and was proving detrimental to the health of the lady of the house. From an examination made under the floor, it appeared as if the two foot space below the floor was not well ventilated, was damp, the beams covered with fungus and the whole formed the main breeding-place of the Psocids, which came up

through the boards and spread over the house. As in the other cases, partial treatment had driven them from room to room.

Fumigation was done as before but using tetrachlorethane instead of carbon bisulphide. 12 lbs. of 130 per cent. sodium cyanide was used, and 12 lbs. of tetrachlorethane. The cyanide was not weighed but divided by eye, as it was in lumps, and 10 lots were used in the house, two small lots in the outside coal cellar and privy. This house was only semi-detached and I feared gas escape to the next house: but the builder assured me this was impossible as there was no communication of any sort.

The fumigation was done with the aid of Mr Scott and Mr Lloyd: forty-eight hours later I visited the house, was able to go straight in and could detect no smell except that of tetrachlorethane when I removed the paper from the outside ventilators leading from the space under the ground floor. There was no complaint from neighbours, no damage to property. The occupiers who were away, returned and have now reported as follows: the house is completely cleared but reinfection has been found to be occurring at a dormer window where insects have been found coming in. This spot has been treated with a miscible wood creosote and varnish and reinfection has ceased. There has been no reinfection from the floors at all and no live insects seen in the house. The cost of treatment was:

	£	*s.*	*d.*
12 lbs. cyanide at 1*s.* 6*d.*	0	18	0
24 lbs. acid at 3*d.*	0	6	0
12 lbs. tetrachlorethane at 1*s.* 6*d.*	0	18	0
	2	2	0

In this case, no particular preparation was made except to open up cupboards, etc.: no damage of any kind was done to anything in the house and the owners are completely satisfied.

In both cases I attribute great weight to the opinion of the lady of the house, utterly distracted and weary of the plague: and in both cases residence in the house after treatment has not been followed by a resumption of the attack.

It is difficult to get cases of this sort but I am satisfied that fumigation with hydrocyanic acid with carbon bisulphide or tetrachlorethane is a feasible and effective method even in a town, provided reasonable precautions are taken. I imagine this fumigation would be effective against every form of insect life except possibly the bed-bug but a house so infected has not been available.

THE LOCUST IN CYPRUS

By W. P. DELANE STEBBING, F.G.S.

The Locust plague in Cyprus which so many early writers have mentioned and which was one of the problems which had to be grappled with on the British occupation in 1878, is now almost a thing of the past. But while locusts are usually thought of as large insects, such as the Syrian species with its orange body and brown-blotched wings, the one which has to be dealt with in the island, and was an annual plague, is a small indigenous brown-marked species of undistinguished appearance known as *Stavronotus cruciatus*. This small locust, which dwells on rocky and poor land from which, in its larval walking and hopping stage, it invades the cultivated areas near by, in its normal state is not migratory nor is the perfect insect able to take long flights. The damage it did was due to its general distribution and to ignorance of the creature's habits. With Eastern fatalism it was a plague of God and that was enough, while there was the inability, intensified by a natural aversion to combine forces, of a poor and sparse population to cope with it.

Like the poor, this locust is always with the islanders and only preventive measures continued from year to year could be satisfactory. The main methods by which the plague has been made negligible are three:

1. Egg collecting—easily done as the egg masses are always laid in light soil bordering the fields.

2. Stopping the crawling larval hosts in their progress by trenches on the further side of which were screens topped with a strip of American cloth. As they were unable to surmount this they fell back into the trench where they were suffocated by those coming after; and

3. Sprinkling feeding areas with a bacterial "cultivation" which gave them an epidemic disease.

It has not been necessary to use the second of these for many years and the annual expenditure on the first is almost negligible; but as a

watchful eye has still to be kept on the trouble there are annual grants for the employment of the third, and a large amount of the "cultivation" is kept in the Government laboratories. But, along with other war economies in Cyprus, agriculture has had to suffer, and although it is said that the locust danger is a thing of the past it is a subject of controversy as to whether the plague has been combatted or if economy has had a say in this matter.

In comparison with the Cyprus locust the Syrian migratory species is a far more formidable creature and its ravages, when it appears, are so much more serious that many of the older accounts must have referred to these invasions from over seas. Several of them speak of flocks of a small bird which suddenly appeared in the island with the insects and ate up so many that the plague was minimised. Van Bruyn recounts how "in the year 1668 throughout the island, but especially in the country round Famagusta, there was such a vast quantity of locusts that when they were on the wing they were like a dark cloud through which the sun's rays could scarcely pierce."

Early in 1915 news reached Cyprus that swarms of locusts were ravaging parts of Syria. Then, that numbers had been found along parts of the coast both north and south of Famagusta in the E. of the island, and that one of our cruisers which put in at that port had passed through a cloud of them on her way and had many settle. The first swarms to arrive were few in number and were not ready for egg laying. A little damage was done in gardens and, as is the Cypriote nature, a great-to-do was made about it; but with the aid of Government grants under the supervision of the Treasury—not the Agricultural Department as one might expect—most of the locusts were caught in the early morning by knocking them off the trees where they clung heavy with the night dews. This measure for the adult insect is the most effective. After egg laying had taken place digging over the soil and collecting the masses was usefully practised, and—after hatching—for both native and foreign species, spraying with a paraffin mixture, the invention of the Entomologist to the Agricultural Department. The egg masses collected came to such an amount that one of the old Turkish storehouses in Famagusta, formerly a church of Venetian date, was filled with them. The sticky eggs are laid by the female in a hole which she bores in the loose soil and form an agglutinated mass covered with grains of earth.

In the latter part of the summer fresh swarms of locusts made their appearance while others were ravaging Egypt. This time some appeared on the northern coast while large numbers invaded spots in the southern

part of the island. Some of these latter did a great deal of damage among the vines and olives but they were not much inclined to settle and start egg laying. Each village did as much as it could to keep them on the move, the inhabitants going out into the fields with sticks and old tins or anything with which they could make a noise. On the uncultivated hill tops piles of brushwood were collected and at the alarm of a swarm of locusts appearing these were fired so that the drifting smoke should terrify the insects. At night the scattered fires now rising now falling in intensity had a rather alarming look from the heights of Troödos before their necessity was realised. The threatened ravaging of the Omodhos district, which is one of the richest wine producing districts of the island, aroused everyone to exert themselves so that little damage was done at this period. A swarm of locusts appeared over the village of Omodhos on the afternoon of its great fair and was heralded by the ringing of its church bells, while departing strangers with their strings of mules and donkeys were hurried on their way by the beating of tin cans. Most of the swarms of this plague, which can have formed only a minute proportion of the hosts that left the shores of Syria, were loosely composed and as they did not darken the sun their fluttering flight was pretty to watch. This flight is very deceptive and made the writer think that he could catch scores of the first swarm he was among. But it was very rare for one to alight and without a butterfly-net it proved impossible to make a capture, although a boy joined in the hunt. On another occasion at midday a swarm was resting among scrub with much bare ground but seemed equally wide awake. Although the insects did not keep in the air no quickness availed to track one to earth as their flight was too long to keep marking the spot at which some particular one dropped.

After the birds among natural destructive agencies there is no doubt that the various species of lizards do an immense amount of good in keeping down insect life. Their numbers prove this. If a mere man could not catch a locust the large ugly brown rock and tree climbing lizard known as *Agama stellio* could: and an attempt to rob one of his prey on the slopes of Troödos above the vineyards was frustrated by his disappearance into a hole. At this level Troödos although tree covered, evidently had no attractions for locusts as the writer only saw a couple of other specimens at any height. It was a complete bar between the cultivated valleys to N. and S.

The vine growing district south of Troödos, which consists of a much denuded belt of decayed volcanic rocks succeeded by a wide limestone

plateau cut up by deep river gorges, is noteworthy in the possession of a factory where wine is made on modern methods and spirits are distilled. The Perapedhi port is well known in the island among the British residents but the firm being largely German, although under British management, and the output going to Hamburg meant the closing down of operations before the vintage of 1915. Up to a late date the manager hoped to run as usual and to profit by the entry of Greece into the war on the Allies' side. This would have meant the flooding of the Alexandria market with cheap Greek wines, the lowering of the prices of the native Cyprus wines and the consequent ability of the Perapedhi Wine Company to buy large quantities at cheap rates from which the firm would have been able to distil spirit at a good profit. But this was not to be and the manager, like many others in their outposts of civilisation, left the island to take up war work in the old country. His garden, which sheltered a swarm of locusts one morning for a few hours, was a wonderful example of productiveness under intelligent management, and of what could be grown in the way of fruit trees which would resist severe winters.

The following quotation from the travel observations of Dr Thomas Shaw on the Syrian locust may close these notes. His life on the southern shores of the Mediterranean gave him good opportunities of observing them. "Those," he says, "which I saw in 1724 and 1725, were much bigger than our common grasshoppers, and had brown spotted wings, with legs and bodies of a bright yellow. Their first appearance was towards the latter end of March, the wind having been for some time from the south. In the middle of April their numbers were so vastly increased, that in the heat of the day they formed themselves into large and numerous swarms, flew in the air like a succession of clouds; and, as the prophet Joel expresses it, they darkened the sun. When the wind blew briskly, so that these swarms were crowded by others, or thrown one upon another, we had a lively idea of that comparison of the Psalmist, of being tossed up and down as the locust."

MUSSEL BEDS; THEIR PRODUCTIVITY AND MAINTENANCE

(THE MUSSEL BEDS OF CARDIGAN BAY)

By FRANK S. WRIGHT.

Zoology Department, University College of Wales, Aberystwyth.

The present paper deals with some of the results of my observations on the mussel beds of Cardigan Bay, from September 1915 to August 1917. These investigations were carried out on behalf of the University College of Wales, Aberystwyth, and included an experimental transplantation of mussels on a fairly extensive scale, in the estuaries at Aberdovey, Barmouth, and Portmadoc. The Cardigan Bay mussel beds had become greatly depleted through over fishing, which, in conjunction with pollution troubles, had brought the fishery to a very low ebb. The work has included outdoor observations, as well as more detailed work in the laboratory. Although the Sea Mussel (*Mytilus edulis*, L.) has received a great deal of attention in the past, and, therefore, some of the facts, *per se*, contained herein may not be new, yet it is believed that their presentation in an especial manner may be useful. The laboratory work has been of a somewhat detailed character, and, although a great deal of time has been devoted to it, much of it remains unfinished. I refer more particularly to that portion which deals with the food material of *Mytilus*, which, while it bears more or less directly upon the subject-matter of the present paper, cannot be more than touched upon here. It is hoped to embody these results in a separate paper at a later date.

The beneficial results to the Cardigan Bay mussel fishery which have resulted from the restocking of the beds (in the spring of 1916, and, less extensively, 1917), as well as the possibility of carrying out the investigations, are due to grants from the Board of Agriculture and Fisheries.

The work was confined mainly to the Dovey Estuary. It is within easy distance of Aberystwyth, the mussel beds there are easily accessible, and a room was used as a laboratory within a few yards of the shore.

This paper is published by kind permission of the Board of Agriculture and Fisheries.

CARDIGAN BAY AND ITS ESTUARIES.

The following account of Cardigan Bay and its more important inlets is, in the main, abridged and otherwise modified from Mr C. L. Walton's description in the first *Report on Investigations towards the Improvement of Fisheries in Cardigan Bay and its Rivers*, published in 1913 by the University College of Wales, Aberystwyth.

Cardigan Bay occupies a considerable portion of the west coast of Wales. It is bounded on the north by the southern shores of Carnarvonshire, and its central portion comprises the entire coastlines of Merionethshire and Cardiganshire, while its southern limit is the North Pembrokeshire coast. It may be said to lie eastward of a line drawn from Braich-y-Pwll in Carnarvon to Strumble Head in Pembroke, which two places are distant some fifty-five miles from each other. The total length of the coastline between these two points is about 140 miles. The whole area is relatively shallow, the thirty fathom limit lying just westward of the line mentioned above. Several causeways or spits (Welsh, *Sarn*, a paved roadway) project out to sea in the northern half of the Bay, often for several miles. Their landward ends are uncovered at low water. Such are Sarn Badrig, Sarn y Bwch, and Sarn Cynfelyn. High and steep cliffs bound the shores of the Bay, except where they are interrupted by the numerous river valleys, and the larger estuaries. We shall omit any mention of the former, as they do not concern us in this place, and confine ourselves to the Estuaries in which the mussel beds are found, namely the Estuary of the Glaslyn and Dwyryd rivers at Portmadoc, the Mawddach Estuary at Barmouth, and the Dovey (or Dyfi) Estuary at Aberdovey. It is in these places that the sea mussel finds the conditions suited to its habits. Patches of mussels occur at various places on the coast, where freshwater influence is felt, but, as the shellfish always remain stunted in growth, they are of no economic value. They might be employed to replenish depleted beds, if necessary.

The tidal sweep, assisted by the south-westerly winds on the west coast, is very strong. Where it meets the rivers, large storm beaches have accumulated, and, fronting the estuaries, sand bars (and sometimes dunes, as at the seaward end of the Dovey Estuary). This tidal sweep causes great alteration of the beaches from time to time, the stone and shingle being transported in a northerly direction along the coastline. C. L. Walton has shown how this factor has had an adverse effect on the fauna in certain parts of Cardigan Bay[1].

[1] "The Shore Fauna of Cardigan Bay," *Journal of the Marine Biological Association of the United Kingdom*. Vol. x, No. 1, November, 1913.

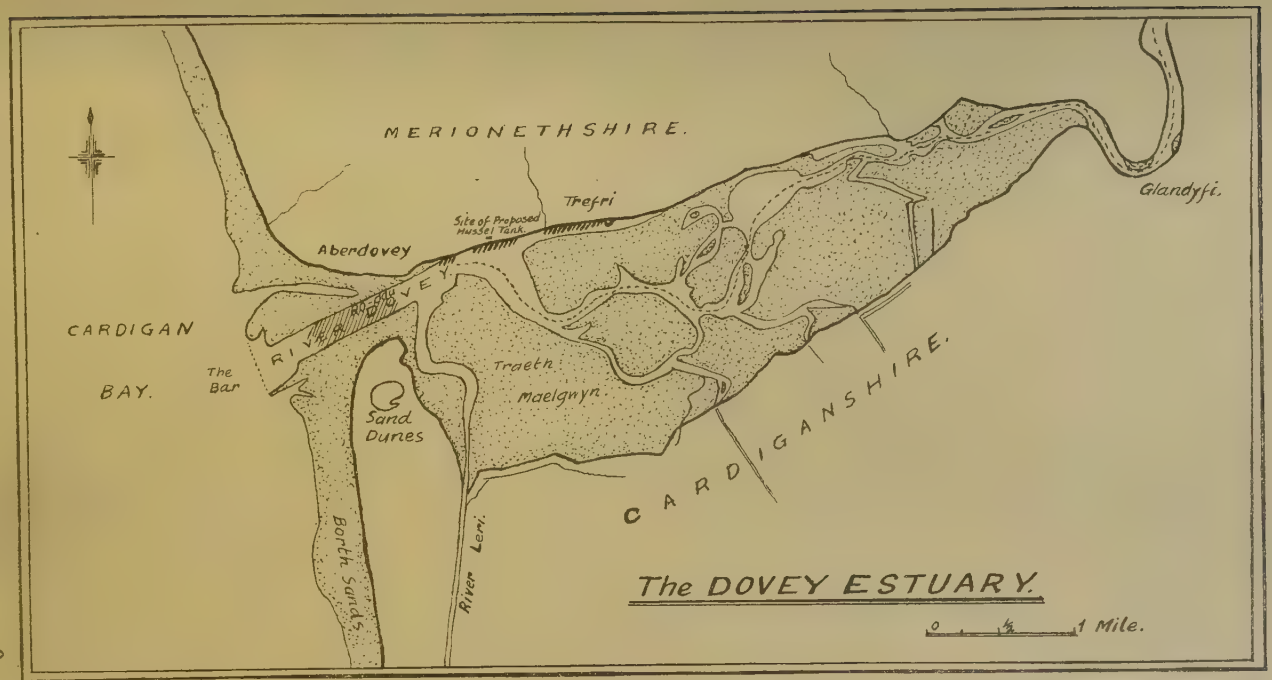

Fig. 1. The Sketch-Map represents the Estuary at low water of ordinary tides. The Mussel Beds are represented—in an exaggerated manner—by means of slanting lines; thick, for the fishing-beds; thin, for the "seed"-bed, or scar. The present course of the River Dovey is, roughly, as indicated on the Map.

THE DOVEY ESTUARY (see Map).

It is necessary to give here a brief description of the Dovey Estuary, and of its mussel beds.

The estuary is a large inlet (some five miles in length), which divides the counties of Merionethshire and Cardiganshire. Its area is approximately five and a half square miles. The north shore is rocky and steep, but, on the south, it is bounded by that low-lying tract which we may term the Dovey Flats. A large sand bar lies across the entry of the estuary, and restricts it to a relatively narrow channel or neck. Such an estuary is termed a "bottle-neck." Within, its condition may best be described as sand-logged, and, consequently, with the exception of the actual channel (or channels) of the river, it is very shallow. Through the great stretches of sand, the river pursues a meandering course to its outlet. Its channel is subject to considerable alteration from time to time, through the agency of the banks of shifting sand. The stable sandbanks are populated by an abundance of cockles and their associates.

Although relatively shallow, it is yet obvious that a very large volume of water is contained in the estuary at high tide. This, having to ebb and flow through one comparatively narrow outlet, is apparently never wholly changed; for instance, within the estuary, the tide will have risen appreciably before it is able to check the outgoing current. Therefore matters constituting a possible source of contamination to the mussels may remain in the channel for a long time.

The river impinges at several points on the north shore, including nearly the whole of that portion fronting the town of Aberdovey and its neighbourhood, and westwards to the Wharf. The current formerly ran along the shore from Trefri to Penhelig Point (east of Aberdovey), but, at the present time, only a shallow gutter marks this old channel. For the most part, these places have been cleared of sand, and they are either rocky, or else covered with stony beaches. This portion of the foreshore shelves moderately gently to low-water mark of spring tides, and then very abruptly to the bed of the river. It is upon such rocky and stony areas (from about low-water mark of ordinary tides downwards), here of limited extent, that the mussel beds are situated. The sea mussel needs hard ground on which to anchor itself; but, where the current is not very swift, and there is a muddy bottom (as at Portmadoc), they are able to maintain themselves by becoming embedded in the mud, or by clinging to each other in clusters.

The history of the Aberdovey mussel beds (and, indeed, of the Cardigan Bay beds in general), is difficult or impossible to trace. It is safe to say that they have suffered many vicissitudes, as, with the slightest deflection of the river channel, portions of the beds are always liable to be covered by the sand, and their population killed. Such accidents have happened time and again: yet the current that destroys one bed may uncover another stony area, that, within a short time, affords a holdfast for a very populous colony of mussels.

The fishing grounds at Aberdovey, then, may be said to comprise a strip of the foreshore on the north shore of the estuary from Trefri Point to the Shipping Wharf, as well as portions of the river bed, etc. Their continuity is broken by occasional patches of sand, but, roughly, the length of the beds may be stated at one mile. Relative to the width of the inlet, this strip is a narrow one, and, in places, exceedingly so.

In all these situations, the mussel thrives satisfactorily, finding an abundance of food material, the necessary degree of freshwater influence, and other conditions suited to its habits.

In the three estuaries there are certain beds (often of large extent and occasionally supporting a crowded mussel population), where the shellfish grow moderately well, while yet never attaining a marketable condition. Such mussel beds will be described hereafter as "scars" (skears), for want of a more convenient term. They generally differ in several respects from the Lancashire mussel beds, properly so designated, however. The population of the Cardigan Bay scars remains poorly fleshed, and their shells, while usually free of *Balanus*, are for the most part very thin and fragile. The last statement applies only to such beds as become dry at long intervals. Otherwise the mussels are often stunted or deformed, thick-shelled, and thickly encrusted with *Balanus*. The repeated wetting and drying to which they are subjected cause the shells to become rough and unsightly. When the chitinous outer shell-layer (the periostracum) is lost, the prismatic layer becomes visible, which, because of its colour, has caused such mussels to be called "blue nebs" among fishermen. A large scar (probably several acres in extent, although, for various reasons, its exact area is difficult to ascertain), or bed of seed mussels occurs at Aberdovey, towards the Bar. It occupies a portion of the north bank of the river, as well as of its bed, and stretches from a short distance below the Wharf to within about half a mile of the Bar. A portion of this bed, on the north shore, becomes uncovered at exceptionally low spring tides, and this place is known locally as *Ro-ddu*.

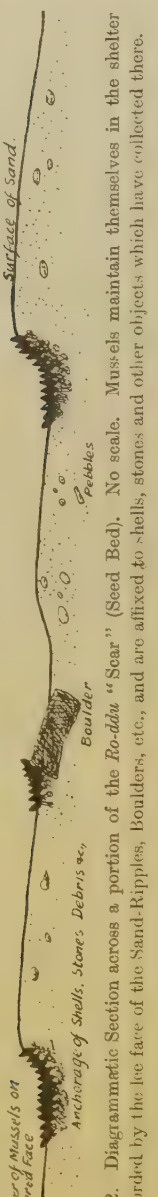

Fig. 2. Diagrammatic Section across a portion of the *Ro-ddu* "Soar" (Seed Bed). No scale. Mussels maintain themselves in the shelter afforded by the lee face of the Sand-Ripples, Boulders, etc., and are affixed to shells, stones and other objects which have collected there.

It will be interesting to note briefly the manner in which portions, at least, of this scar were formed, and how the mussels maintain themselves there (Fig. 2). The substratum is of moderately firm, clean sand, the surface of which is somewhat broken up into sand ripples. The steep (lee) faces of these front in an east-north-easterly direction. Against these ridges, cockle shells (which have been transported downstream by the river current from the extensive beds within the estuary), have accumulated, together with stones, water-logged wood, etc. On these materials, spat liberated by the mussels higher up the river has settled, and continues to settle year by year. As the shellfish develop, their byssus fibres fasten the whole together with a certain degree of firmness. As individual mussels die, they become covered by sand, and their shells afford a still better anchorage to their successors. Thus the bed is composed of a number of small colonies of mussels, clinging to the steeper sides of the sand wave ripples, and sheltered from the direct influence of the tidal current from the sea. Whether the whole of this somewhat "ragged" bed presents the same aspect is doubtful, but there is reason to believe that its deeper portions, which are always submerged, are rather more densely populated.

Lying, as it does, in the narrow neck of the estuary, where the tidal currents race most strongly[1], portions of the scar are probably always covered more or less with sand. This sand may be simply washed over it in quantity, from the river bed, or from banks of shifting sand, or else deposited from that held in suspension by the current, which is considerable (see paragraph on this subject in another place).

Although the sea mussel is an animal of rapid growth, yet, considering the relatively small

[1] Captain Enoch Lewis, of Aberdovey, informs me that, during spring tides, the current in the seaward portion of the estuary reaches a speed of about three miles an hour.

extent of the fishing grounds dealt with in the present paper, it will be understood that these will soon become depleted unless restocked from time to time. It is not legal to take mussels of a size less than $2\frac{1}{4}$ inches, except in certain places (see the Bye-Laws of the Lancashire and Western Sea Fisheries District), and, from the time of the discharge of the ovum, probably three years will elapse before this size is attained, even under favourable conditions. The ova discharged by a single female of *Mytilus* during the spring and summer months are estimated to number from 10,000,000 to 15,000,000[1], the vast majority of which are destined to perish in various ways. So much so indeed, that, in order that the beds may be fished from year to year, it is necessary to restock them at the close of *each* fishing season—a matter of comparative ease.

Myticulture is practised in several different ways[2], but the only one that need be mentioned here is the system of bedding, as practised in Britain. In a limited degree, transplantation has often been carried out by the fishermen concerned, and others, and accounts descriptive of the operations have appeared from time to time. Briefly, the shellfish are removed in quantity, from certain beds (seed beds), where they do not fatten, and redeposited in other situations where growth and fattening proceed with rapidity. Beds of seed mussels are usually present in the vicinity of the fishing grounds, and form nurseries or reservoirs from which they may be restocked when necessary.

The present paper is an attempt to discover the maximum productivity of mussel beds,—we might say the ideal productivity, and, like most other ideals, the present one might perhaps be regarded as unattainable. Yet, even if this should prove to be the case in practice, it is necessary to formulate a working hypothesis, and I venture to believe that an output such as is described later is well within the range of possibility. In its attainment, the chief factor to be taken into consideration is that the population may secure a sufficiency of food material[3], although there are other complicating factors to be considered. The degree of restocking necessary to maintain a maximum yield from the fishing grounds is also dealt with, etc. The data from which most of the subject matter of the present paper has been written, was collected

[1] These figures apply to the American sea mussel, which is, however, of the same species. See article by I. A. Field in *The American Museum Journal*, October, 1916.

[2] See article by Professor W. A. Herdman in the *Report* for 1893 of the Lancs. Sea Fisheries Laboratory.

[3] See article by I. A. Field in *The American Museum Journal*, October, 1916.

during many visits to the Aberdovey (and other) mussel beds. The economic aspect has always been kept in view, but many of the facts contained in the following pages are probably new, or not yet published, and therefore they may possess some degree of scientific value in other respects also.

In concluding these remarks, I shall quote an article by Professor Irving A. Field, whose works are so often mentioned in the following pages: "In the light of our present knowledge it is proper to say, when viewing a shoal of mussels, 'there is one of the greatest organisations in nature for making flesh food by a short and rapid process.' Surely the humble mussel is fulfilling a benevolent mission in the world[1]."

Acreage of the Aberdovey Mussel Beds.

It is not necessary to describe in detail the various beds, where, at Aberdovey, the marketable mussels are fished. It has been said already that they lie on the north shore, towards the seaward end of the estuary, where the slope is often very abrupt. This may be anything up to 50°, such being the slope of the river bank (here of solid rock) at Penhelig Point, just east of Aberdovey. In attempting to estimate the dimensions of the beds, therefore, it is not sufficient to discover merely their length and breadth, but the angle at which the river bank slopes has also to be taken into consideration. These several factors were borne in mind during my endeavours to discover the present superficial area of the fishing grounds, early in the present year (1917). Despite all care to ensure a reasonable degree of accuracy, the figures given below must be understood as being merely approximate. In fact, they are probably considerably below, rather than above, the actual figures.

The approximate total area of the Aberdovey mussel beds is 76,000 square feet (= nearly $1\frac{3}{4}$ acres).

(This does not include the great scar towards the Bar.)

The above figures were obtained from a personal knowledge of the ground, and information supplied by the more experienced fishermen, the whole matter being carefully checked on a large scale map, and in other ways.

Population of the Scars or Seed Areas.

In an endeavour to estimate the maximum potential productivity of mussel beds, when their area is known, it is necessary to find the greatest number of individuals of a given size able to live and thrive per square unit of measurement in natural conditions. Obviously, all

[1] I. A. Field in *The American Museum Journal*, October, 1916.

the individuals in such a unit will not be of the same dimensions, but, in practice (and when checked by other methods) the results have proved fairly accurate.

I found that the only place which fulfilled most of the requirements stated above, as well as certain others to be detailed presently, was the *Ro-ddu* seed area, at Aberdovey. At low water of spring tides, certainly, many areas bearing mussels are readily accessible, but in the majority of them the individuals are very unevenly distributed. It has been said before that the mussels with which we are chiefly concerned here are those from 2″ to 2½″ in length, as, at Aberdovey, the average growth made by a two-inch mussel during the close season is about half an inch (actually $\frac{9}{16}$″).

Therefore, the conditions required in order to obtain this "population factor" were, not only the greatest number of individuals in, say, one square foot, but that all within such unit of measurement should be between 2″ and 2½″ in length.

The sea mussel is fixed in a variety of ways (Fig. 3); if in clusters, the long (antero-posterior) axis may lie in any plane without inconveniencing the shellfish, and the same may be said of it when attached to stones and other solid objects. When, however, it is found living on sandy or muddy bottoms, and more especially when crowded together, or if any force of current is experienced, it generally lives with its anterior or "head" end buried in the substratum, the posterior, or siphonal end, projecting slightly above the surface. The mussel apparently favours these conditions, and I have noticed that newly transplanted mussels soon gather mud and sand around themselves, as described above. In sluggish streams especially, such a posture confers certain advantages with regard to feeding. The siphons will thus be slightly raised above the level of the floor, and, therefore, in a better position to receive the detritus and other food material which washes about there, than if they were more elevated. In this way, a bed of mussels will retard food particles passing through it.

This condition prevails on the *Ro-ddu* Scar, which is occasionally accessible at very low spring tides. By actual count of the individuals (all from 2″ to 2½″ in length) falling within one square foot, I found that the population factor in this place lay somewhere between 121 (11 × 11) and 144 (12 × 12). These figures represent crowded, though not excessively crowded, conditions[1].

[1] For details of overcrowded conditions on mussel beds, etc. see article by Andrew Scott and Thomas Baxter, "Mussel Transplantation at Morcambe," in the *Report* for 1905 of the Lancashire and Western Sea Fisheries Laboratory.

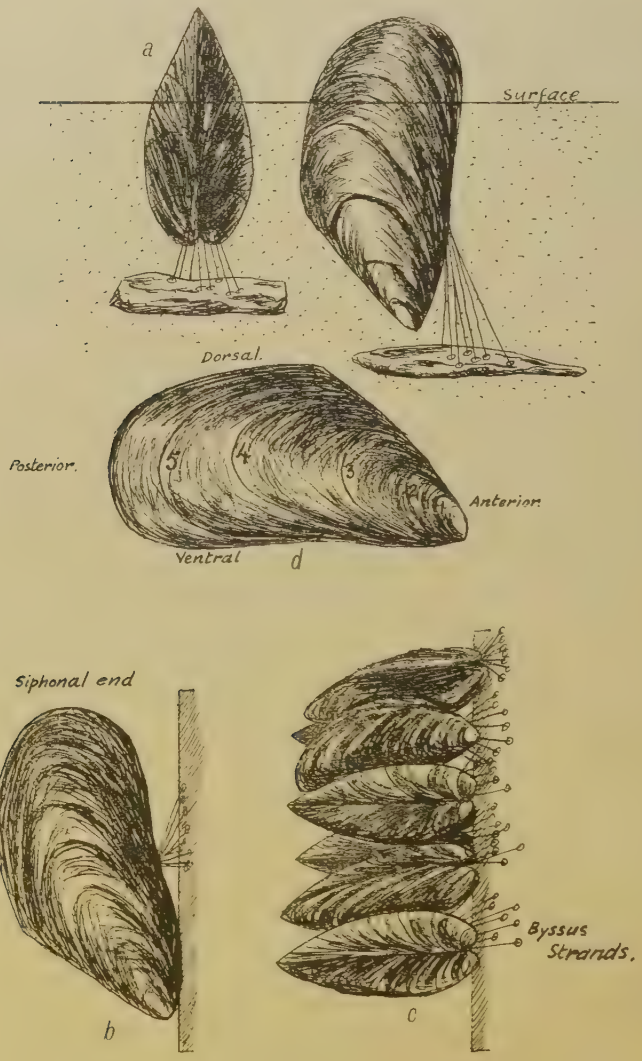

Fig. 3. *Fixation of Mussels, Growth Marks, &c.*

a. Mode of anchorage in a muddy or sandy substratum exposed to currents. *b*, *c*. Mode of fixation to vertical surfaces,—solitary and crowded conditions. *d*. Mussel, with ridges on shell denoting its age. The thick numbered lines are "winter marks,"—therefore, the individual figured is five winters old. It is a "seed" mussel, from the *Ro-ddu* "Scar," Aberdovey. The right side (valve) is shown.

Can we, then, take this result as our ideal population factor, as it stands, and can this numerous population be expected to flourish? In order to determine this point, in view of what is known with regard to the abundant food supply available for the mussel, I conducted the following check experiment. A band of thin iron, 1½″ in depth, was bent into the shape of a square foot, in which were placed mussels, "head" end downwards, 2½″ in the vertical axis, until the measure was well filled. Sufficient space was allowed for each individual to function. They were then counted, and were found to number 121 (11 × 11) individuals. This result is in close agreement with the rougher totals obtained in natural conditions on the *Ro-ddu* seed bed. Therefore, such a number can live and thrive on the fishing grounds, and it may safely be taken as the population factor desired. The poor condition of the mussels on the seed beds is due to a special cause, or a combination of causes, which will be considered immediately.

Such a population obviously cannot be distributed homogeneously over the whole of the fishing grounds, but, even if portions of it have been too thickly restocked, a certain degree of readjustment will take place. The diatoms, and other organisms, vegetable detritus, etc., on which *Mytilus* feeds are present in practically inexhaustible quantity, and every individual in even a populous colony will be able to procure an ample supply of food material for its needs, unless, that is, badly overcrowded conditions cause the water currents to become obstructed in certain cases.

I have examined a large number of mussels from the seed areas (more especially those from *Ro-ddu* Scar, Aberdovey), as well as from the fishing grounds, at different seasons of the year, with regard to their stomach content. Some very interesting, and apparently contradictory facts were noted in this connection, but upon consideration, these will be found to be in accordance with the conditions in which the mussels live.

I have found, for instance, that the stomach content of the seed mussels (poorly fleshed mussels) is generally equal to, and sometimes greater than, that of individuals from the actual fishing grounds, although scientists and others have not hesitated to call the former starved individuals. Also, the organisms, etc., present were, if anything, in greater variety in the case of the mussels from the scars. This state of things needs some explanation, but this attempt to account for the poor flesh-content of the seed muscles must be regarded as tentative. As the beds at Aberdovey are very sharply defined, I confined these observations to this place, for the most part.

The Conditions of Life on the Scars or Seed Areas.

In his book, *Life in the Sea*[1], J. Johnstone, discussing the views of Pütter and others, suggests the possibility that the respiratory and other tissues of certain aquatic animals assist in the assimilation of certain foodstuffs held in solution in the medium in which they are bathed. That, in fact, it may be proved in the future that such tissues function as the chief means[2] in the nutrition of a large number of forms. In the same connection, he calls attention to the relatively large extent of the "so-called respiratory surface of the mollusc or ascidian...," both sedentary forms in which, as might be supposed, "the respiratory function is much less important than it is in the case of a warm blooded animal," because, in them, metabolism proceeds more slowly. He further discusses the possibility of the "anal respiration" of certain of the microcrustacea as being, partially at least, nutritive in character. This hypothesis is a fascinating one, but the experiments of Moore, Edie, and Whitley on the nutrition and metabolism of marine animals[3] seem to disprove Pütter's results. Lobsters (to mention one instance) were kept in seawater, which was regularly renewed, in tightly closed vessels. All plankton was removed from this water before it was introduced into the vessels. The lobsters lived as long as seven months under these conditions. At the end of this time, they frequently registered an increase in weight, but this was found to be due to what may be described shortly as a water-logging of the tissues. As an alternative explanation of the large respiratory surface shown by the types mentioned above (sedentary types), among others, the following suggestion is made. The rate of oxidation in many aquatic animals is very low, a fact which has received somewhat belated recognition. Yet, even so, a relatively large volume of water has to be treated by the organism in order to supply its needs. It is fairly certain that, for various reasons, feeding is often interrupted for longer or shorter periods. Therefore, the taking in of food must be so adapted as to allow of a reserve being accumulated to enable the organism to survive during periods when the supply is cut off. This would go far towards explaining the large respiratory surface in

[1] Cambridge University Press.

[2] Others regard vegetable detritus as the most important element in the food of *Mytilus* and some other forms.

[3] See article in the *Report* for 1913 of the Lancs. and Western Sea Fisheries Laboratory: "The Nutrition and Metabolism of Marine Animals: the Rate of Oxidation and Output of Carbon-dioxide in Marine Animals in Relation to the Available Supply of Food in Sea-Water," by Professor Benjamin Moore, F.R.S., Edward S. Edie, B.Sc., and Edward Whitley, M.A.

the forms under discussion, because in them (most Lamellibranchs, Ascidians, etc.) the cilia of the gill epithelium alone serve as the mechanism of the respiratory streams. A large gill-surface means that a larger volume of water can be treated by those forms possessing it.

Even if the validity of Pütter's theory of "osmotic" nutrition be fully conceded, it does not help us much to understand the poor flesh content of the seed mussels. It must be stated again that, as the *Ro-ddu* Scar is situated near the narrow neck of the estuary, and consequently all the water entering or leaving it has to pass over the bed, any such dissolved food material that may be present higher upstream will have to pass here on its way seaward.

Fouling of the Beds, etc.

The toxic effect of noxious matters liberated in the course of metabolism by large and crowded assemblages of animals, -products of excretion and metabolism,—must now be considered briefly. This factor may be taken as explaining, in some degree at least, the poor condition and high mortality of mussels in those beds which, besides being very crowded, are situated in a sluggish current, where waste products may remain and accumulate to the detriment of the population[1]. When the shellfish are several layers deep, such a condition of things will probably be intensified. On the *Ro-ddu* Scar, however, the animals, though very closely packed, are never overlain by their congeners. Because of this, in conjunction with the great tidal scour to which the place is subjected, the patches of mussels, and the sand in their vicinity, are always remarkably free of noxious substances. Mussel excreta may certainly be detected at times, but in quite negligible amount.

Food Material.

The plentiful and varied nature of the food in the stomach content of mussels from all situations (diatoms, protozoa, detritus, etc.) proves that there is no lack of suitable aliment. Each mussel (as has been explained), in the seed beds will have free access to the water currents, except in certain circumstances to be considered presently. The paucity of diatoms and other organisms, in material collected by means of the tow-net near the mussel beds, compares in an interesting manner with the stomach content of *Mytilus*, with its wealth of organisms. It must be borne in mind, however, that the greater number of diatoms, etc.,

[1] See article by R. L. Ascroft, "Mussel Beds and Mud Banks," in the *Report* for 1898 of the Lancs. and Western Sea Fisheries Laboratory.

entering the mouth of the tow-net, pass out again through the meshes of the silk or other fabric of which the net is fashioned. As the food supply is ample, we are forced to conclude that, for some reason, the individuals are not always able to avail themselves of it.

Silting of the Beds. -

It has been said in the foregoing that parts of the mussel nursery situated towards the Bar at Aberdovey appear to be always covered by sand to a greater or less depth,—not necessarily the same portions all the time. I have never visited this place without observing patches of it in this condition, the buried mussels lying beneath from one to about four inches of sand. As this place dries only at exceptionally low spring tides, when the volume of water entering and leaving the estuary is much greater than normal, we may infer that this "sanding" process is worse at such times than during neap tides. Surface tow-nettings, taken at various states of the tide, reveal the large amount of sand always carried in suspension by the current, both at Aberdovey and in the other estuaries. On the other hand, the sand probably remains longer over any given place during the lesser tides than during springs, when patches covered by one tide may be cleared by the next. The direction and force of the wind are other factors which have considerable influence in this silting process. From some preliminary (incomplete) experiments which I carried out at Aberdovey, under artificial conditions, during the summer of 1916, I found that mussels, despite all care, succumbed in from four to five days when covered by sand. Not only was this the case, but, with even the slightest covering of this material, the mussels made no effort whatever to raise themselves above it, or otherwise to free themselves. Yet a vigorous stream from the exhalent siphon would have cleared them, as the individuals were in a position favourable to such action. This dilemma seems to be one in which the foot might be employed with advantage if it is capable of being utilised as an aid to movement in the adult stage. I have not observed it to be used for this purpose, except in very small individuals, at any time. Although difficult of proof, I am inclined to the view that *Mytilus* behaves in a similar manner when covered by sand in natural conditions. That is, it remains passive, with its normal life processes slowed down, until the sand is removed by the current, or till death supervenes. Fishermen often assert that mussels are able to raise themselves above accumulating mud or sand by the lengthening of their byssus strands, which are attached to underlying stones and other substances. What really happens

is that, as one generation dies and becomes buried (or, perhaps, becomes buried and dies), a new generation grows up, which anchors itself to the shells of its predecessors. So the bank grows, each successive generation accumulating more silt, and, in this manner, covering those beneath[1]. It is not improbable, however, that in natural conditions, it may survive for a somewhat longer period than that mentioned above. Whatever future research may prove to be the true facts, I am convinced that the above factors account, in a large degree, for the poor flesh content of those shellfish living on certain beds which are liable to silting. Covering by sand causes feeding to be interrupted, often for fairly extended periods, whereas, in better situations, it proceeds ceaselessly. There must be a considerable amount of sand held in suspension in the water near the bed of the river, and it is suggested that, often for some hours during each tide, this factor is serious enough to prevent the mussels feeding. They are compelled to remain closed in order to prevent the entrance of sand into the branchial cavity. The views expressed above receive a certain degree of confirmation (although perhaps this is not very definite) from the evidence afforded by the mussel's orientation with regard to the current, when this is a swift one. My curiosity and scepticism were aroused by the following paragraph, as my own experience had led to results opposed to the views stated by its author. In an inaugural address to the Malacological Society[2], B. B. Smith Woodward says: "*Mytilus*, which also comes of a family having a long pedigree, has not a particularly stout test capable of resisting heavy blows, but it meets the waves with its outwardly directed, sharp, wedge-shaped shell and cleaves them instead;...." On the *Ro-ddu* bed, however, where the mussels are buried head foremost in the sand in order to secure a holdfast, I found that, in the majority of cases, the valves, or sides, opposed the currents. Thus, one valve faces upstream, and the other downstream. In this manner, they are probably able to feed for rather longer periods than would be the case if they were placed as stated in the quotation, because of the sand danger. Mussels may, and do, meet the current with their sharp siphonal extremity, but this is probably because they have little choice in the matter, or because the velocity of the current is not great. The quotation is, without doubt, very misleading.

As *Mytilus* does not appear to thrive in purely marine conditions the

[1] See also article by R. L. Ascroft, *op. cit.*

[2] "What Evolutionary Processes do the Mollusca Show?" *Proceedings of the Malacological Society*, Vol. VII, Part 5, June 1907.

more seaward (generally) situation of the seed areas may possibly be a factor to be considered in attempting to account for the light weight of their population. Remembering that the sea mussel is essentially a brackish water animal, it is probably safe to say that its "condition" varies with the difference of freshwater influence.

Growth-Rate of the Sea-Mussel.

The growth-rate of *Mytilus* will be considered here mainly from the economic standpoint, leaving points of more purely scientific interest for another occasion. One point of general interest, and some importance, must be noticed in this place, namely the amount of growth made by *Mytilus* during the first year of its life, in its natural habitat. These observations were made on a suitable portion of the foreshore, near the fishing grounds, at Aberdovey, near low-water mark of spring tides, and they extended over a considerable period. Certain stones were carefully watched, as circumstances permitted, upon which mussel spat was likely to settle (the spawning time probably commences at the end of April, or during May). In due course, young *Mytili* were seen to have affixed themselves thereon, and in July of the following year (1917) they had attained a size varying from $\frac{1}{4}''$ to $\frac{1}{2}''$.

During the course of transplantation work in Cardigan Bay, for two successive years, it has been found that a large proportion of the seed mussels measured about two inches in length. It was desired to ascertain the growth made by these during the close season, which, at Aberdovey and Barmouth, extends from April 1 to October 31 inclusive,—a period of seven months. At Portmadoc, the close season begins a month later, and ends a month earlier, than at the above named places.

Various means were tried of marking large numbers of two-inch mussels, as for instance, by the application of spots of specially prepared paint. This pigment not only hardened under water, and is known to have adhered for some considerable time to the shells, but it left the mussel so marked quite uninjured. The attrition of water-borne sand, however, removed all trace of it in the course of time, and to my disappointment, not a single marked mussel has been recovered from any of the beds. As a check experiment, some cages of galvanised iron wire were constructed at the same time, and these were deposited in the river at Barmouth. Some of them were recovered at the commencement of the next fishing season, and the surviving mussels were carefully measured. As the cages would seem to have been affected by the shifting sand that has lately covered portions of the Barmouth mussel beds, the

results obtained are not of great value. Other cages, more carefully constructed, were placed in the river at Aberdovey, and have not yet been recovered. It is feared that a recent "creep" of the foreshore may have buried them.

Despite these setbacks, however, some valuable data has been amassed with regard to the growth of *Mytilus* during the close season. Upon removal from the poor areas (seed beds), the transplanted mussels make such rapid shell, as well as flesh growth, that usually a distinct ridge is formed on the shell, which marks off its older portion from the newer growth. When removed from a poor to a better situation, this mark is so definite and unmistakable, that it is impossible to doubt its meaning (Fig. 3). At the commencement of the fishing season (*i.e.* after the transplanted mussels had spent about seven months on the fishing beds), I examined a large number of individuals, which, from certain unmistakable indications, had been brought from the poorer situations. The average increase in length made by a two-inch mussel in this time was found to be rather more than half an inch (actually $\frac{9}{16}$″).

Growth Rate of the Sea Mussel.

Size of mussel	Locality	When transplanted	When recovered	Average increase in length	Length of growth period in days	Number examined
2″ (5·1 cm.)	*Ro-ddu* seed bed	March 30, 1916				Several hundreds
2½″ (6·4 cm.)	Near Literary Institute, Aberdovey		Nov. 15, 1916	½″ (actually $\frac{9}{16}$″)	231	Several hundreds

Now let us consider the increase in cubic content which this growth in length represents,—reckoning the latter at half an inch. The following figures were obtained by placing in water a large number of individuals (sometimes singly, sometimes more than one), in a partially filled measuring glass graduated in cubic centimetres. In each case, the valves were carefully tied with cotton to keep them in apposition, as any water entering them would have resulted in too low a reading. A number of shells were also treated in a similar manner, and the readings for them, being deducted from the total mass including the shells, give the correct figures for the valve content. This of course includes flesh, air, water, etc.

Average Cubic Content of Mytilus as measured by Water Displacement.

Size of mussel	Cubic content (including shell)	Displacement of shell only	Actual cubic content of valves	Increase	Length of growth period in days	Number examined
2″ (5·1 cm.)	10 c.c.	3·3 c.c.	6·7 c.c.			Several hundreds
2½″ (6·4 cm.)	22·5 c.c.	5·0 c.c.	17·5 c.c.	10·8 c.c.*	231	Several hundreds

* This represents an increase of, roughly, 161 %.

Weight Experiments.

A considerable number of mussels was utilised in the determination of the figures given below. The average weight probably varies considerably at different seasons of the year, and, during the summer months especially, I have found that mussels are often poorly fleshed and of light weight. They increase in weight in autumn and winter. The figures here represent the weights of fairly heavy, unspawned individuals.

Average Weight of Mussels in Shell (Live Weight).

Size of mussel	Weight (including shell	Locality	Date	Increase	Length of growth period in days	Number examined	Remarks
2″ (5·1 cm.)	14 gms.	*Ro-ddu* seed bed, Aberdovey	March 30, 1916			Several hundreds	Unspawned (fairly heavy) individuals
2½″ (6·4 cm.)	30 gms.	Fishing grounds, Aberdovey	Nov. 15, 1916	16 gms.*	231	Several hundreds	Fairly heavy mussels

* This represents an average increase in weight of about 114 %.

Average Weight of Soft Parts (Flesh Content).

In the case of a soft bodied creature like the sea mussel, which secretes an abundance of mucus, it will be understood that it is difficult or even impossible to determine accurately what is organic matter and what not, in the fresh condition. A rough method of estimating the flesh content is, therefore, of no use whatever. Special methods have to be employed, and these have to be followed with great care if the results are to prove of any value.

In order to determine the readings given below, a number of mussels of the required measurement were heated until they maintained a constant weight in an air oven at a temperature of 100° to 105° C. The shells and byssus fibres were of course removed. At the conclusion of the period of desiccation the weights of the residues were determined by a balance, and the average weight calculated.

I am greatly indebted to Dr T. Campbell James, of the Edward Davies Chemical Laboratory, U.C.W. Aberystwyth, who kindly worked out these results, and who is responsible for the figures given in the following table.

Average Dry Weight of Organic Matter (Flesh Content).

Size of mussel	Average weight of dry organic matter (flesh)	Locality	Date	Increase	Number examined	Remarks
2″ (5·1 cm.)	0·949 gms.	*Ro-ddu* seed bed, Aberdovey	Mid April. 1916		6	Unspawned mussels
2½″ (6·4 cm.)	2·027 gms.	Fishing grounds. Aberdovey	November, 1917	1·078* gms.	6	Heavy mussels

* Therefore, the approximate increase in flesh content made during the close season is 114 %.

The Maximum Potential (Ideal) Productivity of the Aberdovey Mussel Beds, and its Money Value.

At Aberdovey, theoretically, a "bag" of mussels, as packed for export, contains one hundred pounds of the shellfish. Actually, it weighs about 125 lbs. in order "to allow for the decrease of weight consequent on the loss of moisture during transit to the various market centres."

It was necessary to estimate, approximately, the number of mussels of different sizes contained in a bag of 125 lbs. In order to do this, several pounds of each of the sizes required were weighed, and the number per bag calculated from the figures so obtained.

We have seen already that 121 mussels each 2½″ in length can thrive in a space of one square foot. Let us assume that the Aberdovey beds are populated to this extent. We see that, in order to fill one bag with 2½″ mussels, the total population of nearly fourteen square feet is required. The estimated total area available for mussel culture at

Aberdovey is some 76,000 square feet[1], which, if stocked to its utmost capacity, would number a population of 9,196,000 individuals[2]. This number would suffice to fill, roughly, about 5659 bags.

Number of Mussels contained in a bag of 125 *lbs. as determined by weight.*

Size of mussel	Approximate no. per bag of 125 lbs.	Locality	Date	Number of lbs. weighed	Remarks
2″ (5·1 cm.)	3250 individuals	Wall at Penhelig, Aberdovey	July 19, 1917	8 lbs.	Old and thick-shelled mussels
2½″ (6·4 cm.)	1625 individuals	Wall at Penhelig, Aberdovey	July 19, 1917	6 lbs.	Old and thick-shelled mussels
2¾″ (7 cm.)	1312* individuals	Fishing grounds, Aberdovey	August 4, 1917	6 lbs.	Thin-shelled mussels

* This number is probably too high. The shells of these individuals were less thick and consequently lighter than those of the other sizes given. By actual count of the mussels (averaging about 2¾″) in a measure, three of which the fishermen count as one bag, I estimated that about 1100 individuals of this size went up to make a bag of 125 lbs.

The average price per bag received by the fishermen throughout the season may be taken at about five shillings,—sometimes rather less and often above. Therefore, taking this sum as the unit value per bag, the whole yield, as calculated above, should represent a value in money of something near £1414. 0*s*. 0*d*.[3]

If twenty men were regularly employed in the mussel fishery at Aberdovey throughout the fishing season of five months, counting this period as twenty weeks, this sum of money, if equally distributed, should mean that each man would earn a wage of £3. 10*s*. 0*d*. per week.

It must be admitted that such an intensive yield might prove impossible of realisation in practice, but the difficulties are not so insuperable as they appear on a casual consideration. Returns not very far short of the figures given above might reasonably be expected if the

[1] This does not take into account walls, piles, etc., which afford a holdfast to hosts of mussels of all sizes.

[2] Thus, the progeny of a single female mussel, if all survived, would suffice to populate the entire fishing beds at Aberdovey! (see paragraph in another place).

[3] It is estimated that about thirty tons of mussels were *exported* from Aberdovey during the season 1916–17. At 5*s*. per bag, this represents a value of only £150. Had the demand held, a much greater quantity could have been marketed, and, therefore, the river is fairly well stocked for next season's fishing. Cooperation between the fishermen is the great need of the local mussel fishery.

necessary amount of restocking is carried out with due care. A good deal of space would be occupied by individuals below the legal size, down to very minute mussels which have developed from the spat. These, however, would occupy the interstices between the larger mussels, to a considerable extent, and, at all events, the space which they occupy would be compensated by those larger mussels living in clusters, and by the increased superficial area of the ground resulting from inequalities in its surface.

Restocking the Beds (*Transplantation*).

We shall assume that, at the close of the fishing season, the beds have been exhausted of mussels of the legal size (two and a quarter inches, and above). It is now necessary to estimate the amount of transplantation requisite in order that the maximum yield may be maintained in the following autumn, and the distribution among the fishermen each his proper share in this work.

In the first place, it is necessary to gauge how far the beds are already stocked with mussels below the legal size, which have either not been brought up in the course of fishing, or else have been thrown back when the men cleaned their catches. This is a somewhat difficult matter, as obviously conditions will vary in different areas. Still, knowing something of the rapidity of the mussel's growth rate, it will probably not be very wide of the actual state of things if we assume that one-fourth of the area is intermittently stocked in this way. Therefore, three-fourths of the ground will need to be replenished by means of transplantation. This, at Aberdovey, represents some 57,000 square feet, and, if we aim at placing 121 individuals (in this case each of 2″ in length[1]), it involves the removal and deposition of 6,897,000 individuals. This number would fill, roughly, 2122 bags, and represents 106 tons of shellfish.

Most of the boats used in this fishery, at Aberdovey and elsewhere, are fairly large ones, each capable of carrying one ton or slightly over. This means that, if the maximum amount of transplantation is carried out, a boat, under the most favourable conditions, would need to make one hundred and six journeys with its maximum load of one ton[2] of seed mussels. A single boat could only procure this large cargo during a very low spring tide, when the seed bed dries, and the mussels are simply shovelled into it. If gathered by means of a rake, it would scarcely be possible for a single boat, with a crew of one, to procure

[1] As a 2″ mussel will increase to 2½″ in seven months, this growth has to be allowed for.

[2] This amount was often exceeded during the transplantation experiments at Aberdovey, even when the crew consisted of one person only.

more than half this quantity per tide. But if, as we have supposed to be the case, twenty men were working at the fishery, and that all of them assisted in the transplantation, removing one ton per tide per man, the whole amount could be removed in, roughly, ten journeys per boat.

The scar may be supposed to dry for about four or five days during low spring tides, or, even if it does not actually dry, the depth of water covering it will be negligible, and, therefore, the whole operation could be carried out in the space of two spring tides. If additional assistance were forthcoming, the time occupied would be further lessened. Thus boats from a neighbouring port might be requisitioned for a few days, their owners assisting; such services to be repaid in kind later. The mussels should be transplanted prior to spawning.

Some Destructive Influences, etc.

It has been mentioned before, that mussel beds, when affected by strong currents, are liable to much destruction through becoming undermined, when large masses become detached. These felted masses are swept out to sea and destroyed. The wastage of spat is simply incredible, if, indeed, it is to be regarded as wastage. Myriads of creatures feed upon the larvae, both in the brief free-swimming stage and after fixation. I believe that frost has been known to destroy large numbers of mussels in beds subject to its influence, but I am unable to quote any authority for this statement, at the moment. I have not remarked such an effect in Cardigan Bay.

The chief fish consumers of young mussels are those belonging to the Pleuronectid family,—Plaice, Dab and Flounder. Skate are caught near the seed areas at Aberdovey, and it is not unlikely that they feed upon the thin-shelled population of these areas.

Fishermen assert that Herring Gulls, Oyster Catchers, etc., favour a dietary of mussels, and, certainly, whenever the *Ro-ddu* area becomes dry, large numbers of these birds resort to it. Scott adduces evidence confirmatory of this statement, and found traces of mussels in gulls' excreta, while Field gives a list of birds feeding on mussels in America[1].

Several carnivorous molluscs attack the mussel, but the only one that need be mentioned here is the Dog Whelk (*Purpura lapillus* L.), which may sometimes be detected in the act. Mussel shells bearing a neatly drilled hole are not uncommonly found[2], clear testimony of the attacks of a gastropod culprit.

[1] See article by I. A. Field in *The American Museum Journal*, October, 1916.
[2] *Ibid.*

In the branchial chamber of large mussels there is frequently present a small crab (*Pinnotheres pisum*). An examination of the stomach content of several of these crustacean "messmates" of *Mytilus* revealed the presence therein of the diatoms and other materials[1] utilisable by the mussel itself as food, but diverted by the crabs to their own use. I have remarked that it is never (or very rarely), found within the valves of the seed muscles, which, as we have seen, are poorly nourished. This is significant, because, as they are frequent in mussels from the fishing grounds, it would appear that the partnership is a profitable one from the crab's point of view. I have noticed that, in certain cases, where the female *Pinnotheres* had attained a relatively large size, it would seem to have exerted considerable pressure on portions of the mantle lobes, and upon the shell beneath. In some instances, this pressure had caused the nacreous or pearly layer to be dissolved away, probably by the action of pathogenic matters secreted by the cells of the mantle at the points affected. Thus, the presence of *Pinnotheres* (although it may not be parasitic in the strict meaning of the term), is probably more or less harmful to its host. By fishermen and dealers alike, *Balanus*-encrusted mussels are regarded with great disfavour, because, by rendering the appearance of the shellfish unsightly, their market value is considerably reduced. My own observations tend to show, however, that, so far from being an unmitigated nuisance near mussel-beds, *Balanus* may actually prove of some benefit to young mussels. The spat tends to settle (or, rather, to remain) on stones, etc., which are encrusted by numbers of *Balanus*, while other stones in the vicinity, although to all appearance equally suitable, are frequently barren. A *Balanus*-covered surface certainly offers a good attachment, and I have frequently remarked young *Mytili* growing up and thriving actually within the "parapet" of *Balanus*, the original tenant of which had died. I have no doubt that large numbers of larval *Mytili* receive their start in life through the agency of the *Balanus* colonies. The nauplius and cypris stages of *Balanus* larvae are not uncommonly present in the stomach content of *Mytilus*, and they probably form a not inconsiderable part of its food in spring and early summer. The Common Starfish (*Asterias rubens*, L.) is a notorious enemy of the mussel. It is occasionally found on the seed beds at Aberdovey, and elsewhere in Cardigan Bay, but, being anything but numerous in these situations, it cannot be classed as a serious pest.

[1] *The Food Value of Sea Mussels*, by I. A. Field, Government Printing Office, Washington, U.S.A.

During my examination of the stomach content of *Mytilus*, I found that Nematodes were present in a large number of individuals. The matter is being investigated, and these thread worms may prove to be true parasites.

The above will suffice to show that, as regards animal foes, the amount of damage wrought in the Cardigan Bay mussel areas is inconsiderable. Indeed, their activities may be regarded as positively beneficial in their effects, inasmuch as they serve to thin the crowded population of the scars to some small extent.

C. L. Walton[1] has found that mussels adherent to vertical rock faces, piles, etc., break away and fall to the ground when they attain a length of $2\frac{1}{2}''$ to $3\frac{3}{4}''$, and a weight in correspondence. It is suggested that this happens only where the mussels are subjected to frequent changes of medium, and not when always bathed in water.

Seaweed, when present in quantity near mussel beds, is often the cause of a high rate of mortality among the shellfish, which are apt to become smothered beneath masses of it. "Eel Grass" (*Zostera* sp.) and the commoner *Ulvae* may be cited in this connection. This source of danger, again, is rarely or never serious in Cardigan Bay.

Industrial pollution of rivers and estuaries may sometimes affect mussel beds in an adverse manner. At the present time, I am investigating the probable effects of plumbism on mussels from Aberystwyth Harbour, 99 % of which show a singularly uniform malformation in shell growth.

The greatest calamity to which mussel beds are subjected, however, is that of becoming silted over by shifting sand. Whole beds are often destroyed in this manner, as referred to in the foregoing.

Sand is also important in this connection in quite a different way. In August 1917, I received a sample of fairly large mussels from the entrance to the Harbour at Pwllheli. The shellfish were fairly well fleshed, but extraordinarily light in weight. This was owing to the fact that the attrition of water borne sand and shingle had worn away a large part of the two outer shell layers. Practically, only the innermost (pearly) layer remained to protect the animal at the anterior end, and, although this was relatively thick, it is improbable that, in such conditions, many individuals would survive for any great length of time.

[1] *The Food Value of Sea Mussels*, by I. A. Field, Government Printing Office, Washington, U.S.A.

The Portmadoc Mussel Beds.

Description of the Fishing Grounds.

The mussel beds at Portmadoc are situated in the River Glaslyn, near Portmadoc, and, lower down the river, at Borth-y-Gest, there are certain small mussel-bearing areas. The latter are not important at the present time, and need not be described here.

The chief beds lie (*a*) at Llyn bach (above the Ffestiniog railway bridge), (*b*) in the Dock, and, turning sharply in a north-easterly direction, the latter bed follows (*c*) the "gutter" or channel behind the New Quay. Scattered beds of small extent exist in the vicinity of the Slate Wharf and Ballast Bank, rather lower down stream.

The current here is comparatively tranquil, and, for the most part, the mussels maintain themselves on the substratum (mixed sand and mud) in bunches or clusters. The population in all the above areas is very abundant. Extensive seed beds adjoin the fishing grounds.

Acreage of the Portmadoc Mussel Beds, etc.

The figures given below were estimated from a large scale map of the district, and checked from my own knowledge of the fishing grounds. These occupy the more or less level bed of the river, and, therefore, it is not difficult to gain an approximate idea of their superficial area by such methods. This is, roughly, 400,000 square feet (rather above nine acres).

Assuming, as before, an ideal population of 121 mussels per square foot over the whole of this surface, we get the large total of 48,000,000 individuals ($2\frac{1}{2}$" in length). This figure represents a total of 29,784 bags (approximately), and, in terms of money, a sum of £7446. 0*s*. 0*d*. Reckoning, as for Aberdovey, the amount of transplantation necessary to maintain this large production, we find that it involves the deposition of 554 tons (nearly). It would not be possible to procure this large amount of seed in Portmadoc itself, and, therefore, this factor might be regarded as governing the output of these beds. Near Pwllheli, however, there is a very large seed bed, the population of which is available to restock the Portmadoc fishing grounds, if necessary.

Should intensive myticulture ever be practised in this country, methods will have to be devised in order to increase the amount of space available for the settlement of spat. The plan of mapping out the many beds of poorly nourished mussels on various parts of the coast has been

suggested. Some of these are fairly populous, and they exist wherever the influence of freshwater is felt, and there is suitable ground. These beds should be surveyed, and their population estimated, in order to be prepared for the possible failure of the usual sources of seed mussels. These small colonies are stocked automatically by the spat liberated by mussels in their vicinity, but more favourably situated. They represent a very small proportion of that which is washed out to sea and destroyed in various ways. They form a never failing, if not very considerable, source for the replenishment of the fishing grounds, which, by means of low stakes, or by diverting the stream to flow over a greater area of beach, could doubtless be considerably developed with a small outlay. This matter deserves serious attention. That the seed beds (generally more seaward in situation) may fail is no remote contingency, and such has been the case at Barmouth during 1916 and 1917. The winter storms and spring floods have resulted in serious damage being done to the beds, and several years may elapse before they regain their former dense population.

The Barmouth Mussel Fishery.

With regard to Barmouth and its mussel fishery, only a few words can be said in this place. The beds are of small extent, and always covered by a considerable depth of water. Since they are also situated on steeply shelving banks, their area is difficult to estimate exactly. If well stocked, they might give a maximum yield of mussels to the value of £300 or £400. These figures, however, are not based upon actual calculations, but, when all the factors are taken into consideration, they are probably not very wide of the potential production.

Purification of Mussels.

Most (and probably all) of the rivers and estuaries of Great Britain suffer from sewage and industrial pollution, in varying degrees. Sewers and drains empty into them, and also the effluents from factories and works on their banks. The sewage is often permitted to escape in an untreated condition, and this is the state of affairs that prevails in the Cardigan Bay estuaries, which, on the other hand, suffer very little from industrial waste products. This condition of things is obviously very unsatisfactory when considered in relation with the mussel beds, and extensive bacteriological analyses of water taken in relation with the fishing grounds reveal the presence of bacteria resembling those found

in the human colon (*Bacillus coli communis* etc.), often in numbers too great to be ignored. Mussels may also contain through inhibition of contaminated water, "*Bacillus typhosus* (producing enteric fever), and, possibly *B. enteritidis* (producing Gaertner poisoning)." These last are, luckily, much more rare in this connection. Even though we need not place implicit trust in the findings of bacteriological science, which has to rely upon indirect methods or reactions in its determinations of these minute organisms, yet we see that the matter is serious enough. It is probable that (admitting the validity of their identification), their sojourn in the mussels' digestive tract, or in salt or brackish water, may have so changed the character of the bacteria as to render them generally harmless to man, or, at least, less harmful.

It will be remembered that, in a previous paragraph, it was stated that the water in the Cardigan Bay estuaries was never wholly changed in any one tide. Thus, impurities washing about in the river bed may remain there for a considerable time, and the significance of this factor now becomes apparent. Under such conditions (which affect the areas now being discussed), the occurrence of, for example, a single case of enteric, could bring about an immediate cessation of the fishing in the place affected. Therefore, it becomes necessary to effect the purification of the shellfish in order to safeguard the industry, no less than in the interests of the public health.

A crude method of "purification" is sometimes practised by the fishermen at certain places. After cleaning ("spinning") the mussels, they are placed in bags, which are left to wash for a day or two in the tide, where the water bathing them is known to be reasonably free from contamination. This rough method cannot be said to have the desired effect, for reasons now to be stated. According to recent views, any bacteria which the mussel may harbour are present in the animal's rectum; that is, in the faecal matter not yet extruded by the animal. Now, although mussels treated in the manner described above will speedily excrete such waste products, these, being retained by the closely woven fabric of the sacking, only serve to re-infect the shellfish.

Mussel purification tanks are projected to be erected (one is already in use at Barmouth), in connection with the Cardigan Bay mussel beds, under the supervision of the Lancashire and Western Sea Fisheries Committee. They are solidly built concrete structures, in several compartments, on the wooden grids on the floor of which the mussels are placed, in layers not exceeding three deep. They are designed to fill over the top at about high water of neap tides, when the mussels will

rest under a depth of about two feet of clean sea water. As the faecal matter is ejected, it falls through the gratings on to the cemented floor beneath, which slopes away to outlet pipes of large diameter. The water is allowed to escape when the tide is low, and carries, as it flows out, the excretory products. Exhaustive tests (bacteriological and others) are carried out before the site of the tank is decided upon, in order to ensure the purity of the water gaining access to it. The shellfish remain in the structure for the space of forty-eight hours, and they are then put into bags bearing the lead seal of the Committee, to show that they have undergone treatment.

Another method, now being experimented with in this country, employs certain chemical substances, which cause the mussels to eject speedily all waste matters, and at the same time sterilises the water.

The capacity of these structures is limited to present day needs, and, therefore, if the industry is to be developed to its utmost limit, as outlined in the present article, these purification arrangements must be so designed as to expand with it.

In this article, it has been attempted to show the means whereby suitable "ground" in estuaries may be made to produce a greatly increased yield of mussels. Great efforts are being made in the U.S.A. to popularise this shellfish as an article of food, in view of its high nutritive value. In Europe, no such efforts are required, as its value has long been recognised. It is hoped that representative persons living in settlements where mussels are fished regularly will take up the matter, and encourage the fishermen to keep the beds well stocked,—work well worth the doing, from the standpoint of food production as well as in other ways. In the small seaside communities of Cardigan Bay, for instance, the mussel fishery forms practically the sole source of income to a fair number of men, who would otherwise be unemployed for long periods during which there is no other work for them to do. In these places, however, the industry, which has been shown to be capable of very considerable development, suffers because of the utter lack of cooperation between its members, and means must be devised to overcome this evil. A frequent cause for complaint by the fishermen is that they have no security of tenure, which however seems unavoidable. They ask to be granted the leasehold of portions of the beds, in which case, they assert, they would undertake to keep their respective "small holdings" stocked to their fullest capacity. This is open to objection, however, even were it possible to accede to their wishes. Most of our

British mussel beds are liable to much destruction from time to time, through silting and other causes. Thus, the leasing of portions of the mussel beds would simply give cause for further dissatisfaction. Co-operation between themselves, on the other hand, and their prior claim to the limited accommodation afforded by the mussel-cleansing tanks, would render their molestation by outsiders an impossibility. At the present time, most fishermen (on the west coast of Wales, at least), cannot be made to realise that regularity of supply creates a steady market.

I have now to thank those gentlemen who have kindly assisted me during the progress of the work, and in the preparation of this paper. I am greatly indebted to Dr J. Travis Jenkins, the Superintendent of the Lancashire and Western Sea Fisheries Committee, for much advice and assistance. Mr W. E. Whitehouse, and Mr C. L. Walton, both of the U.C.W. Aberystwyth, have also greatly assisted me in many ways. I have to thank Captain Enoch Lewis, of Aberdovey, for allowing me the use of a room as a laboratory.

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